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ABSTRACT

This manual provides information on all phases of air navigation for navigators and student navigators in training. It develops the art of navigation from the simplest concepts to the most advanced procedures and techniques. The text contains explanations on how to measure, map, and chart the earth; how to use basic instruments to obtain measurements of direction, altitude, temperature, and speed; and how to solve basic navigation problems by dead reckoning and map reading. Special techniques used to navigate by radio, radar, and Loran; by using celestial concepts and procedures; and in polar areas are covered. There is information on flight publications, weather services, mission planning, inflight procedures, and low level navigation. The final chapters cover automatic navigation systems and aerial delivery. (Extensive diagrams, illustrations and photographs are included together with attachments on symbol definitions and term explanations.) (Author/KP)

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AIR NAVIGATION

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DEPARTMENTS OF THE AIR FORCE AND THE NAVY

DEPARTMENTS OF THE AIR FORCE
AND THE NAVY
Washington DC 20330

AF MANUAL 51-40
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CHAPTER 1

Introduction

DEFINING AIR NAVIGATION

The word *navigator* comes from two Latin words, *navis,* meaning ship, and *agere,* meaning to direct or move. Navigation is defined as the process of directing the movement of a craft from one place to another. The craft may be in its broadest sense any object requiring direction or capable of being directed. Unlike sea or naval navigation, air navigation involves movement above the surface of the earth within or beyond the atmosphere. Air navigation, then, can be defined as "the process of determining the geographical position and of maintaining the desired direction of an aircraft relative to the surface of the earth." Other terms, "avigation" and "aerial navigation" have fallen into disuse in favor of the term, "air navigation." Certain unique conditions are encountered in air navigation that have a special impact on the navigator.

- *Need for continued motion.* A ship or land vehicle can stop and resolve any uncertainty of motion or await more favorable conditions if necessary. Except to a limited extent, most aircraft must keep going.
- *Limited endurance.* Most aircraft can remain aloft for only a relatively short time, usually a matter of hours.
- *Greater speed.* Navigation of high speed aircraft requires detailed flight planning and navigation methods and procedures that can be accomplished quickly and accurately.
- *Effect of weather.* Visibility affects the availability of landmarks. The wind has a more direct effect upon the position of aircraft than upon that of ships or land vehicles. Changes of atmospheric pressure and temperature affect the height measurement of aircraft using barometric altimeters.

Some form of navigation has been used ever since man has ventured from his immediate surroundings with a definite destination in mind. Exactly how the earliest navigators found their way must remain to some extent a matter of conjecture but some of their methods are known. For example, the Phoenicians and Greeks were the first to navigate far from land and to sail at night. They made primitive charts and used a crude form of dead reckoning. They used observations of the sun and the North Star, or pole star, to determine direction. Early explorers were aided by the invention of the astrolabe (see figure 1-1), but it was not until the 1700's that an accurate chronometer (timepiece) and the sextant were invented making it possible for navigators to know exactly where they were, even when far from land.

Any purposeful movement in the universe ultimately involves an intention to proceed to a definite point. Navigation is the business of proceeding in such a manner as to arrive at that point. To do this safely is an art. Navigation is considered both an art and a science. Science is involved in the development of instruments and methods of navigation as well as in the computations involved. The skillful use of navigational instruments and the interpretation of available data may be considered an art. This combination has led some to refer to navigation as a "scientific art."

As instruments and other navigational aids have become more complicated, an increasing proportion of the development has been shifted from the practicing navigator to the navigational scientist who aids in drawing together the applications of principles from such sciences as astronomy, cartography, electronics, geodesy, mathematics, meteorology, oceanography, and physics. Such applica-

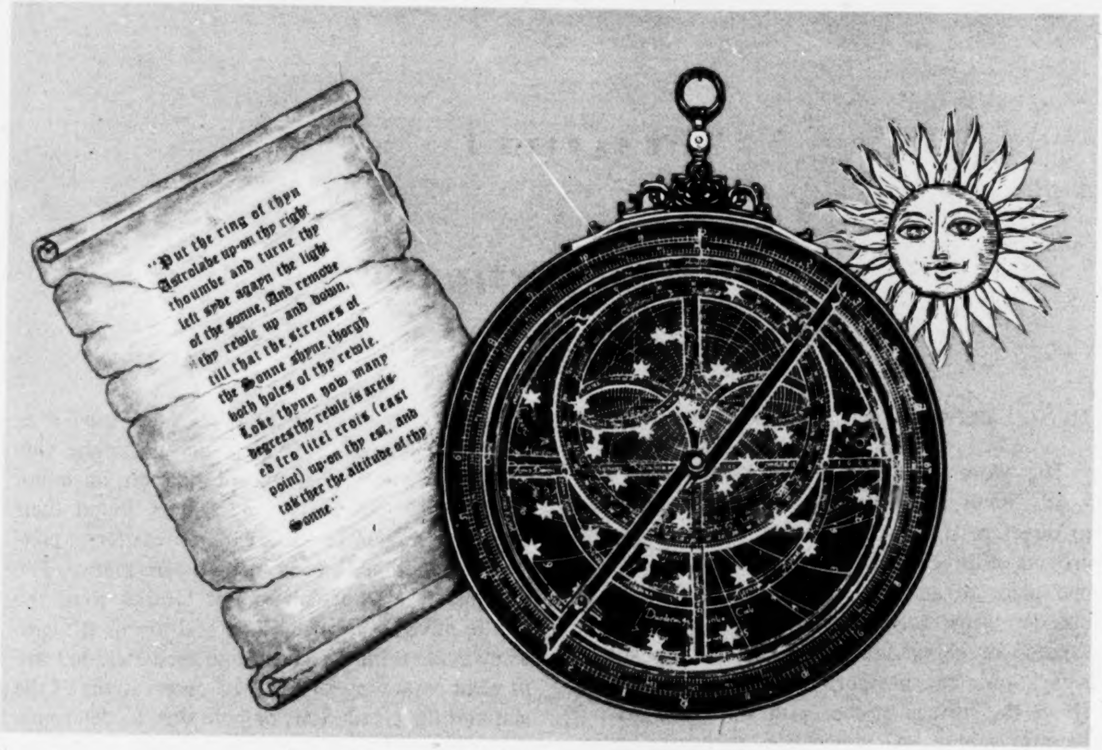

"Put the ring of thyn
Astrolabe up-on thy right
thoumbe and turne thy
left syde agayn the light
of the sonne. And remove
thy rewle up and down,
till that the stremes of
the Sonne shyne thorgh
both holes of thy rewle.
Loke thynn how many
degrees thy rewle is areis-
ed fro litel crois (east
point) up-on thy est, and
tak ther the altitude of thy
Sonne."

Figure 1-1. The Ancient Astrolabe

tions aid in explaining navigational phenomena and in developing improvements in speed, accuracy, or routine actions in practicing the "scientific art" of navigation.

The beginning navigator largely practices the science of navigation; that is, he gathers data and uses it to solve the navigation problem in a more or less mechanical manner. It is not until after many hours of flying that the navigator begins to realize that his total role involves an integration based on judgment. The navigator builds accuracy and reliability into his performance by judgment based upon experience. The military navigator is an indispensable part of many offensive and defensive missions. He must be able to plan a mission covering every eventuality; inflight, he must be able to evaluate the past and current progress of the aircraft and to derive a correct conclusion for the remainder of the mission. High speed navigation demands that he have the ability to anticipate changes in flight conditions—to think ahead of the aircraft—and to make the correct decision immediately on the basis of anticipated changes.

AIR NAVIGATION PROBLEM

The problem of air navigation is, primarily, to determine the direction necessary to accomplish the intended flight, to locate positions, and to measure distance and time as means to that end.

When navigation is performed without "aids," that is, without obtaining or deducing position information from special equipment specifically designed to provide only momentary knowledge of position, the basic method of navigation, "dead reckoning," is used.

Dead reckoning is the determination of position by advancing a previous position, using only direction and speed data. The navigator does this by applying, to the last well-determined position, a vector or a series of consecutive vectors representing the magnitude and direction of movement that has been made since the previous position. The new position obtained is for a specific time and is essentially a predicted or theoretical position. The navigator assumes that he can use direction and speed data previously determined with reasonable accuracy to obtain a future position.

The most important elements in the plotting of a dead-reckoning position are elapsed time, direction, distance, and speed. Knowing these and his starting point, a navigator can plot his approximate position, which in turn, can serve as a base for a subsequent course change.

When the function of air navigation is performed with "aids" to navigation, the navigator can provide a new and separate base or starting point from which to use dead reckoning procedures. When an aid to navigation provides the navigator with a position or fix, any cumulative errors in previous dead-reckoning elements are cancelled. In effect, the navigator can restart the mission, as far as the future is concerned, from each new fix or accurate position determined by the use of aids.

An adjective is often used with the word, "navigation," to indicate the type or primary method being used, such as *dead reckoning* navigation, *celestial* navigation, *radar* navigation, *pressure pattern* navigation, *doppler* navigation, *grid* navigation, *inertial* navigation, etc.

SOURCES OF NAVIGATION INFORMATION

In addition to this manual, several other sources provide complete or partial references to all methods and techniques of navigation. Some of these are:

- U. S. Navy Oceanographic Office, *Air Navigation,* H.O. Pub 216. This is a general reference book for air navigators.
- U. S. Navy Oceanographic Office, *American Practical Navigator,* Bowditch, H. O. Pub 9. An epitome of navigation, this text provides a compendium of navigational material. Although designed primarily for the marine navigator, it has valuable application for the air navigator.
- United States Naval Institute, *Navigation and Piloting,* Dutton. This is a teaching text for the elements of marine navigation.
- Air Training Command, *Navigation for Pilots,* ATCM 51-7. This manual explains the basic principles and procedures of air navigation used by pilots and information on the navigation systems used by other crew members of multi-place aircraft.
- U. S. Air Force, *Navigator Refresher Course,* AFP 60-1-1, 60-2, and 60-3. This is a programmed text and ground mission primarily used for navigators requiring annual refresher training.
- USAF, Air Training Command, *The Navigator,* USAFRP 50-3, published three times per year by ATC. This magazine contains a variety of articles from world-wide sources that relate to navigation and which advance new and different means for accomplishing techniques of navigation.

The following United States Observatory and U.S. Navy Oceanographic Office publications are also prescribed for Air Force use:

- Air Almanac
- American Ephemeris and Nautical Almanac
- H.O. Pub 9 (Part II), "Useful Tables for the American Practical Navigator"
- H.O. Pub 211, "Dead Reckoning Altitude and Azimuth Tables"
- H.O. Pub 249, "Sight Reduction Tables for Air Navigation"

The Department of Defense (DOD) Catalog of Aeronautical Charts and Flight Publications published by the Defense Mapping Agency (DMA), contains information on the basis of issue and procedures for requisitioning these publications. The use of the Air Almanac and H.O. 249 Tables is discussed in detail later in this manual.

SUMMARY

Some form of navigation has been accomplished since the ancient Greeks and Phoenicians began sailing far from land. The problems of air navigation and the navigator today are far different from those experienced by these ancient mariners. With the advent of newer and higher speed aircraft, the navigator must be able to quickly and accurately make decisions which directly affect the safety of the aircraft and the crew. Using proven techniques and modern aids, the navigator practices a scientific art.

CHAPTER 2

Earth and Its Coordinates

INTRODUCTION

Basic to the study of navigation is an understanding of certain terms which could be called the dimensions of navigation. These so-called dimensions of *position, direction, distance, and time* are basic references used by the air navigator. A clear understanding of these dimensions as they relate to navigation is necessary to provide the navigator with a means of expressing and accomplishing the practical aspects of air navigation. These terms are defined as follows:

- *Position* is a point defined by stated or implied coordinates. Though frequently qualified by such adjectives as "estimated," "dead reckoning," "no wind," and so forth, the word "position" always refers to some place that can be identified. It is obvious that a navigator must know his position before he can direct the aircraft to another position or in another direction.
- *Direction* is the position of one point in space relative to another without reference to the distance between them. Direction is not in itself an angle, but it is often measured in terms of its angular distance from a reference direction.
- *Distance* is the spatial separation between two points and is measured by the length of a line joining them. On a plane surface, this is a simple problem. However, consider distance on a sphere, where the separation between points may be expressed as a variety of curves. It is essential that the navigator decide exactly "how" the distance is to be measured. The length of the line, once the path or direction of the line has been determined, can be expressed in various units; e.g., miles, yards, and so forth.
- *Time* is defined in many ways, but those definitions used in navigation consist mainly of two: (1) the hour of the day and (2) an elapsed interval.

The methods of expressing position, direction, distance, and time are covered fully in appropriate chapters. It is desirable at this time to emphasize that these terms, and others similar to them, represent definite quantities or conditions which may be measured in several different ways. For example, the position of an aircraft may be expressed in coordinates such as at certain latitude and longitude. The position may also be expressed as being 10 miles south of a certain city. The study of navigation demands that the navigator learn how to measure quantities such as those just defined and how to apply the units by which they are expressed.

EARTH'S SIZE AND SHAPE

For most navigational purposes, the earth is assumed to be a perfect sphere, although in reality it is not. Inspection of the earth's crust reveals that there is a height variation of approximately 12 miles from the top of the tallest mountain to the bottom of the deepest point in the ocean. Smaller variations in the surface (valleys, mountains, oceans, etc.) cause an irregular appearance.

Measured at the equator, the earth is approximately 6,887.91 nautical miles in diameter, while the polar diameter is approximately 6,864.57 nautical miles. The difference in these diameters is 23.34 nautical miles, and this difference may be used to express the ellipticity of the earth. It is sometimes expressed as a ratio between the difference and the equatorial diameter:

$$\text{Ellipticity} = \frac{22.34}{6{,}887.91} = \frac{1}{295}$$

Since the equatorial diameter exceeds the polar diameter by only 1 part in 295, the earth is very nearly spherical. A symmetrical body having the same dimensions as the earth, but with a smooth surface, is called an oblate spheroid.

In figure 2-1, Pn, E, Ps, and W represent the surface of the earth, and Pn-Ps represents the axis of rotation. The earth rotates from W to E. All points in the hemisphere Pn, W, Ps approach the reader, while those in the opposite hemisphere recede from him. The circumference W-E is called the equator, which is defined as that imaginary circle on the surface of the earth whose plane passes through the center of the earth and is perpendicular to the axis of rotation.

Great Circles and Small Circles

A great circle is defined as a circle on the surface of a sphere whose center and radius are those of the sphere itself. It is the largest circle that can be drawn on the sphere; it is the intersection with the surface of the earth of any plane passed through the center.

The arc of a great circle is the shortest distance between two points on a sphere, just as a straight line is the shortest distance between two points on a plane. On any sphere, an infinitely large number of great circles may be drawn through any point, though only one great circle may be drawn through any two points that are not diametrically opposite. Several great circles are shown in figure 2-2.

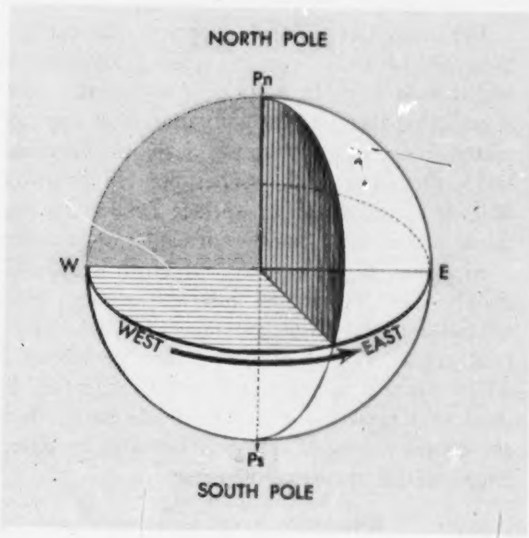
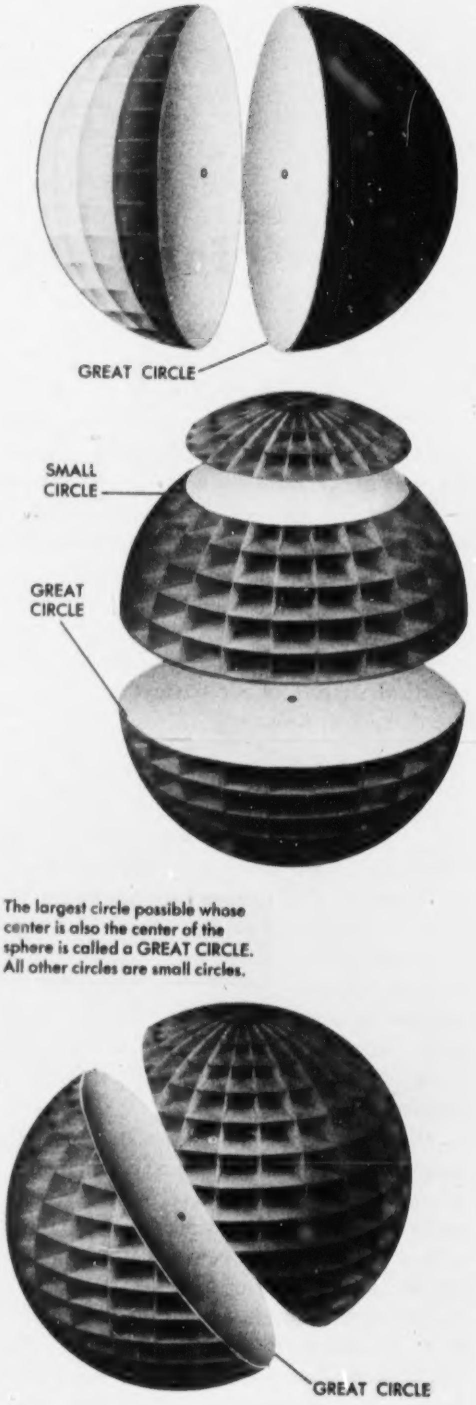


Figure 2-1. Schematic Representation of the Earth Showing Axis of Rotation and Equator



The largest circle possible whose center is also the center of the sphere is called a GREAT CIRCLE. All other circles are small circles.

Figure 2-2. A Great Circle is the Largest Circle in a Sphere

Circles on the surface of the sphere other than great circles may be defined as small circles. A small circle is a circle on the surface of the earth whose center and/or radius are not that of the sphere. A special set of small circles, called latitude, is discussed later.

In summary, the intersection of a sphere and a plane is a circle—a great circle if the plane passes through the center of the sphere, and a small circle if it does not.

Latitude and Longitude

The nature of a sphere is such that any point on it is exactly like any other point. There is neither beginning nor ending as far as differentiation of points is concerned. In order that points may be located on the earth, some points or lines of reference are necessary so that other points may be located with regard to them. Thus the location of New York City with reference to Washington D. C., is stated as a number of miles in a certain direction from Washington. Any point on the earth can be located in this manner.

Such a system, however, does not lend itself readily to navigation, for it would be difficult to locate a point precisely in mid-Pacific without any nearby known geographic features to use for reference. A system of coordinates has been developed to locate positions on the earth by means of imaginary reference lines. These lines are known as parallels of latitude and meridians of longitude.

LATITUDE. Once a day, the earth rotates on its north-south axis which is terminated by the two poles. The equator is constructed at the midpoint of this axis at right angles to it (see figure 2-3). A great circle drawn through the poles is called a meridian, and an infinite number of great circles may be constructed in this manner. Each meridian is divided into four quadrants by the equator and the poles. Since a circle is arbitrarily divided into 360 degrees, each of these quadrants therefore contains 90 degrees.

Take a point on one of these meridians 30 degrees north of the equator. Through this point pass a plane perpendicular to the north-south axis of rotation. This plane will be parallel to the plane of the equator as shown in figure 2-3 and will intersect the earth in a small circle called a parallel or parallel of latitude. The particular parallel of latitude chosen is at 30° N, and every point on this parallel will be at 30°N. In the same way, other parallels can be constructed at any desired latitude, such as 10 degrees, 40 degrees, etc.

Bear in mind that the equator is drawn as the

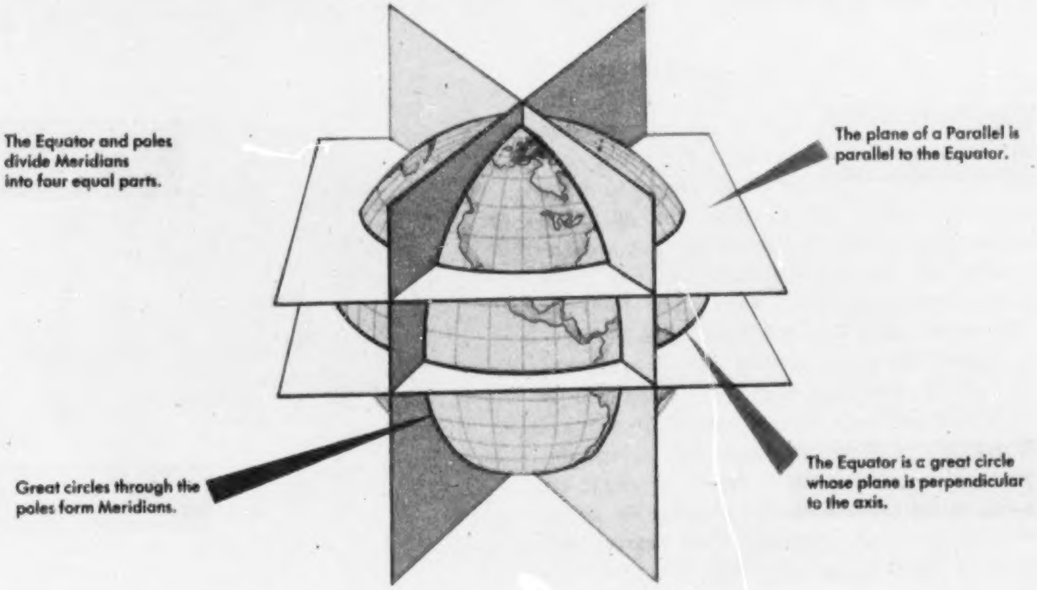

The Equator and poles divide Meridians into four equal parts.
The plane of a Parallel is parallel to the Equator.
Great circles through the poles form Meridians.
The Equator is a great circle whose plane is perpendicular to the axis.

Figure 2-3. Planes of the Earth

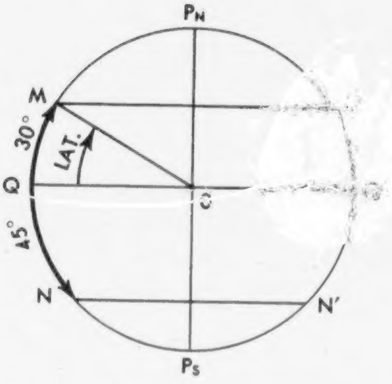


Figure 2-4. Latitude of M is Angle QOM or Arc QM

great circle midway between the poles, that the parallels of latitude are small circles constructed with reference to the equator, and that they are definitely located small circles parallel to the equator. The angular distance measured on a meridian north or south of the equator is known as latitude (see figure 2-4) and forms one component of the coordinate system.

Longitude. The latitude of a point can be shown as 20° N or 20° S of the equator, but there is no way of knowing whether one point is east or west of another. This difficulty is resolved by use of the other component of the coordinate system, longitude, which is the measurement of this east-west distance.

There is not, as with latitude, a natural starting point for numbering, such as the equator. The solution has been to select an arbitrary starting point. A great many places have been used, but when the English speaking people began to make charts, they chose the meridian through their principal observatory in Greenwich, England, as the origin for counting longitude, and this point has now been adopted by most other countries of the world. This Greenwich meridian is sometimes called the prime or first meridian, though actually it is the zero meridian. Longitude is counted east and west from this meridian through 180 degrees, as shown in figure 2-5. Thus, the Greenwich meridian is the 0 degree longitude on one side of the earth, and after crossing the poles, it becomes the 180th meridian (180 degrees east or west of the 0-degree meridian).

Summary. If a globe has the circles of latitude and longitude drawn upon it according to the

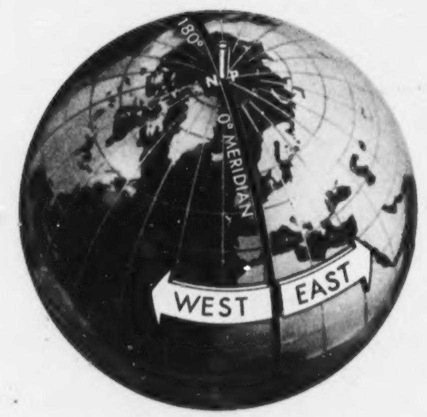


Figure 2-5. Longitude is Measured East and West of Greenwich Meridian

principles described, and the latitude and longitude of a certain place have been determined by observation, this point can be located on the globe in its proper position. (See figure 2-6.) In this way, a globe can be formed that resembles a small-scale copy of the spherical earth.

It may be well to point out here some of the measurements used in the coordinate system. Latitude is expressed in degrees up to 90, and

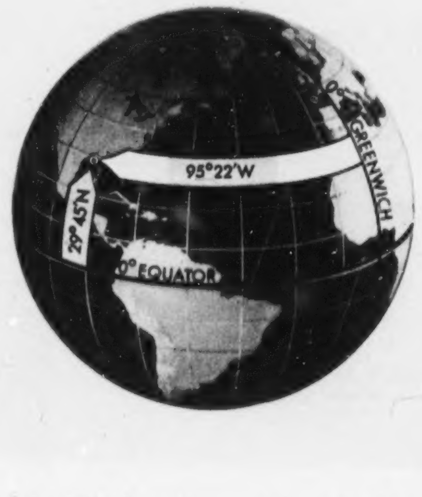


Figure 2-6. Latitude is Measured from the Equator; Longitude from the Prime Meridian

longitude is expressed in degrees up to 180. The total number of degrees in any one circle can not exceed 360. A degree (°) of arc may be subdivided into smaller units by dividing each degree into 60 minutes (′) of arc. Each minute may be further subdivided into 60 seconds (″) of arc. Measurement may also be made, if desired, in degrees, minutes, and tenths of minutes.

A position on the surface of the earth is expressed in terms of latitude and longitude. Latitude is expressed as being either north or south of the equator, and longitude as either east or west of the prime meridian.

Distance

Distance as previously defined is measured by the length of a line joining two points. In navigation the most common unit for measuring distances is the nautical mile. For most practical navigation purposes, all of the following units are used interchangeably as the equivalent of one nautical mile:

- 6,076.10 feet (nautical mile).
- One minute of arc of a great circle on a sphere having an area equal to that of the earth.
- 6,087.08 feet. One minute of arc on the earth's equator (geographic mile).
- One minute of arc on a meridian (one minute of latitude).
- Two thousand yards (for short distances).

Navigation is done in terms of nautical miles. However, it is sometimes necessary to interconvert statute and nautical miles. This conversion is easily made with the following ratio:

In a given distance:

$$\frac{\text{Number of statute miles}}{\text{Number of nautical miles}} = \frac{76}{66}$$

Closely related to the concept of distance is speed, which determines the rate of change of position. Speed is usually expressed in miles per hour, this being either statute miles per hour or nautical miles per hour. If the measure of distance is nautical miles, it is customary to speak of speed in terms of knots. Thus, a speed of 200 knots and a speed of 200 nautical miles per hour are the same thing. It is incorrect to say 200 knots per hour unless referring to acceleration.

Direction

Remember that direction is the position of one point in space relative to another without reference to the distance between them. The time-honored point system for specifying a direction as north, north-northwest, northwest, west-northwest, west, etc., is not adequate for modern navigation. It has been replaced for most purposes by a numerical system.

The numerical system, figure 2-7, divides the horizon into 360 degrees starting with north as 000 degrees, and continuing clockwise through east 090 degrees, south 180 degrees, west 270 degrees, and back to north.

The circle, called a *compass rose,* represents the horizon divided into 360 degrees. The nearly vertical lines in the illustration are meridians drawn as straight lines with the meridian of position A passing through 000 degrees and 180 degrees of the compass rose. Position B lies at a true direction of 062 degrees from A, and position C is at a true direction of 295 degrees from A.

Since determination of direction is one of the most important parts of the navigator's work, the various terms involved should be clearly understood. Generally, in navigation unless otherwise stated, all directions are called *true* (T) directions.

- *Course* is the intended horizontal direction of travel.
- *Heading* is the horizontal direction in which an aircraft is pointed. Heading is the actual orientation of the longitudinal axis of the aircraft at any instant, while course is the direction intended to be made good.
- *Track* is the actual horizontal direction made by the aircraft over the earth.

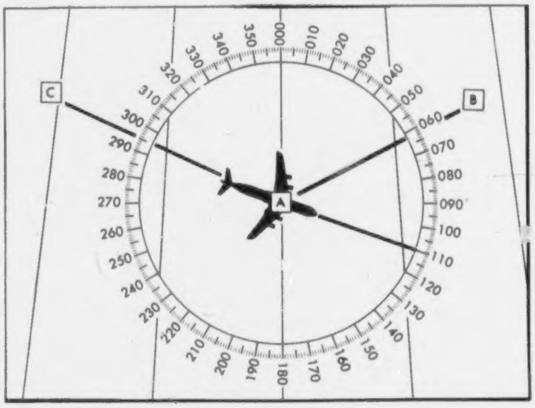


Figure 2-7. Numerical System is Used in Air Navigation

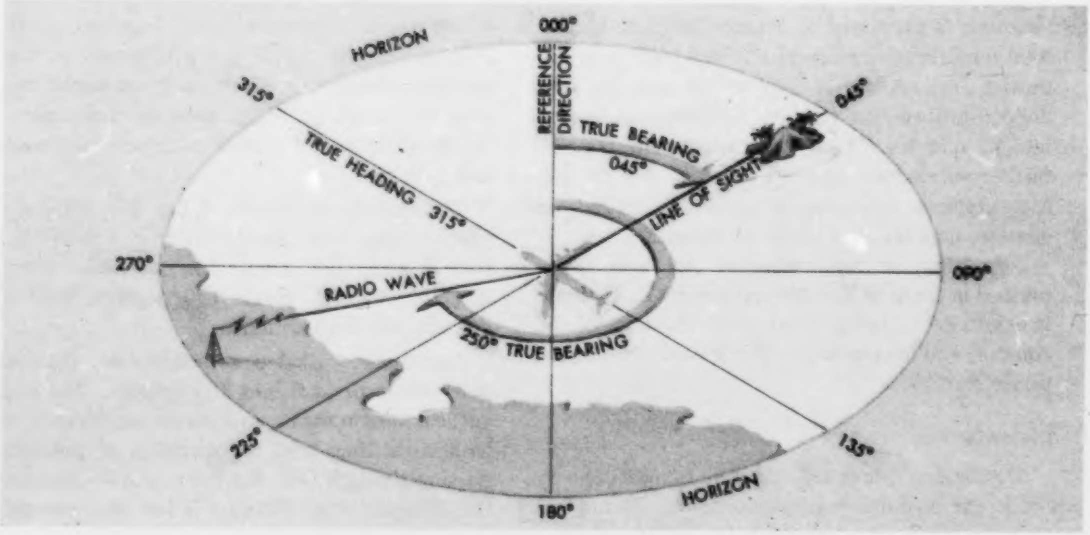

000°
HORIZON
REFERENCE DIRECTION
315°
045°
TRUE BEARING
045°
TRUE HEADING 315°
LINE OF SIGHT
270°
090°
RADIO WAVE
250° TRUE BEARING
225°
135°
180°
HORIZON

Figure 2-8. Measure True Bearing from True North

• *Bearing* is the horizontal direction of one terrestrial point from another. As illustrated in figure 2-8 the direction of the island from the aircraft is marked by the line of sight (a visual bearing). Bearings are usually expressed in terms of one of two reference directions: (1) true north, or (2) the direction in which the aircraft is pointed. If true north is the reference direction, the bearing is called a *true bearing*. If the reference direction is the heading of the aircraft, the bearing is called a *relative bearing* as shown in figure 2-9. A complete explanation of these terms and their use in navigation is given in a later chapter of the manual.

Great Circle and Rhumb Line Direction

The direction of the great circle, shown in figure 2-10, makes an angle of about 50 degrees with

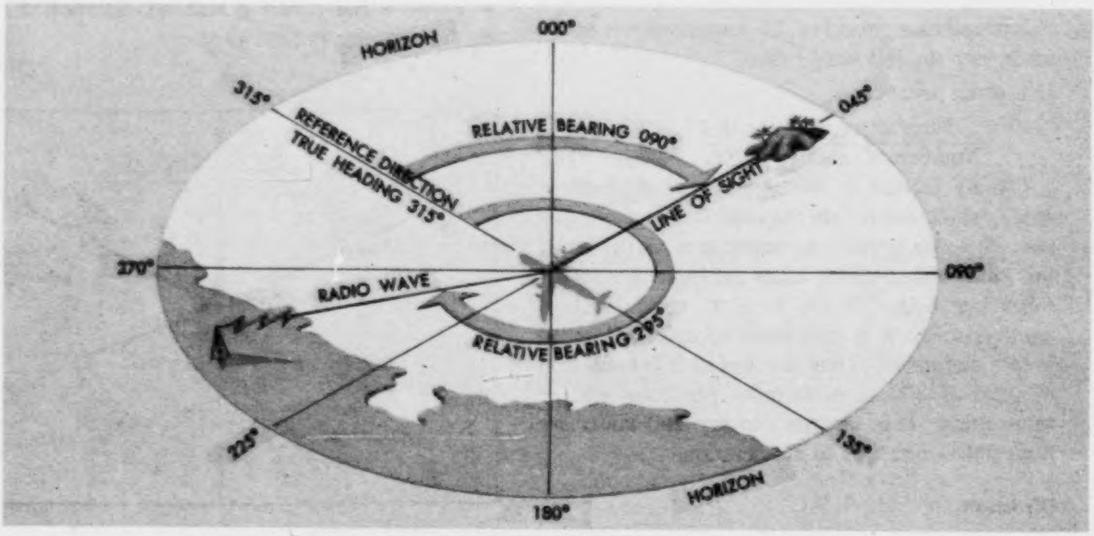

000°
HORIZON
315°
045°
REFERENCE DIRECTION
TRUE HEADING 315°
RELATIVE BEARING 090°
LINE OF SIGHT
270°
090°
RADIO WAVE
RELATIVE BEARING 295°
225°
135°
180°
HORIZON

Figure 2-9. Measure Relative Bearing from Aircraft Heading

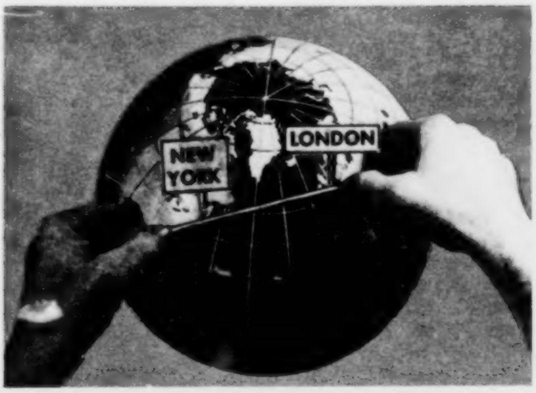

NEW YORK
LONDON

Figure 2-10. Great Circle and Rhumb Line

the meridian of New York, about 90 degrees with the meridian of Iceland, and a still greater angle with the meridian of London. In other words, the direction of the great circle is constantly changing as progress is made along the route, and is different at every point along the great circle. Flying such a route requires constant change of direction and would be difficult to fly under ordinary conditions. Still, it is the most desirable route, since it is the shortest distance between any two points.

A line which makes the same angle with each meridian is called a rhumb line. An aircraft holding a constant true heading would be flying a rhumb line. Flying this sort of path results in a greater distance traveled, but it is easier to steer. If continued, a rhumb line spirals toward the poles in a constant true direction but never reaches them. The spiral formed is called a *loxodrome* or loxodromic curve as shown in figure 2-11.

Between two points on the earth, the great circle is shorter than the rhumb line, but the difference is negligible for short distances (except in high latitudes) or if the line approximates a meridian or the equator.

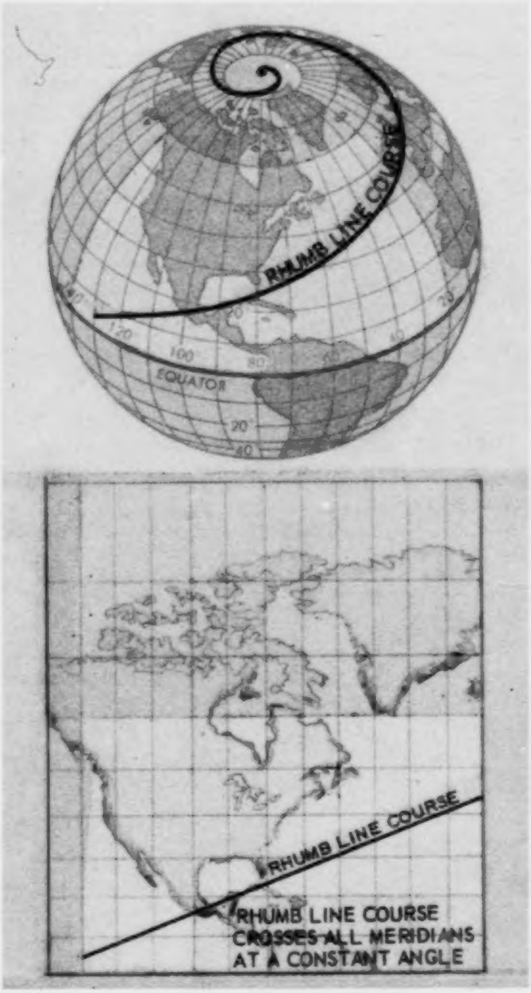

RHUMB LINE COURSE
EQUATOR
120
100
80
60
40
20
20
40
RHUMB LINE COURSE
RHUMB LINE COURSE
CROSSES ALL MERIDIANS
AT A CONSTANT ANGLE

Figure 2-11. A Rhumb Line or Loxodrome

CHAPTER 3

Maps and Charts

INTRODUCTION

The history of map making is as old as history itself. The primitive peoples made rough maps on clay tablets as early as 2500 B. C. Since their maps were mere sketches of small areas, such as estates and villages, they required little geographic control. Moreover, the earth was considered flat, so the need for a projection did not arise. The idea of a spherical earth confronted the early cartographers with the basic projection problem of portraying the earth's spherical surface on a flat surface. Hipparchus (160-125 B. C.), the inventor of trigonometry, originated the basic azimuthal projections—the orthographic and the stereographic—which are in use to this day. From the time of Hipparchus to the present jet age, there has been continuing advancement in the devising of new map projections.

Basic Information

Before launching into the discussion of the projections used on the various types of aeronautical charts, the reader should become familiar with certain basic ideas and definitions relative to charts and projections in general.

- A map or chart is a small scale representation on a plane surface of the surface of the earth or some portion of it. Such a representation designed for navigational purposes is generally termed a "chart"; however, the terms "map" and "chart" are used interchangeably.
- A chart projection is a method for systematically representing the meridians and parallels of the earth on a plane surface.
- The chart projection forms the basic structure on which a chart is built and determines the fundamental characteristics of the finished chart. The positions and alignments of chart details such as roads, rivers, mountains, cities, airfields, etc., are controlled by their relationship to the projection. The relationship of position (distance and direction) of one feature to another on the chart is therefore determined by the characteristics of the projection, which must be understood in order to recognize the true relationships on the earth from the picture as presented on the chart.
- There are many difficulties which must be resolved when representing a portion of the surface of a sphere upon a plane. If you try to flatten a piece of orange skin, you will find that the outer edge must be stretched or torn before the central part will flatten into the plane with the outer part. Likewise, the surface of the earth cannot be perfectly represented on a flat surface without distortion. Distortion is misrepresentation of direction, shape, and relative size of the features of the earth's surface.

Note that you can flatten a small piece of orange peel with comparatively little tearing, stretching, or wrinkling, for it is nearly flat to begin with. Likewise, a small area of the earth, which is nearly flat, can be represented on a flat surface with little distortion. However, because the curvature of the earth is pronounced, distortion becomes a serious problem in the mapping of large areas.

Distortion cannot be entirely avoided, but it can be controlled and systematized to some extent in the drawing of a chart. If a chart is drawn for a particular purpose, it can be drawn in such a way as to minimize the type of distortion which is most deterimental to the purpose. Surfaces that can be spread out in a plane without stretching or tearing such as a cone or cylinder are called developable surfaces, and those like the sphere or spheroid

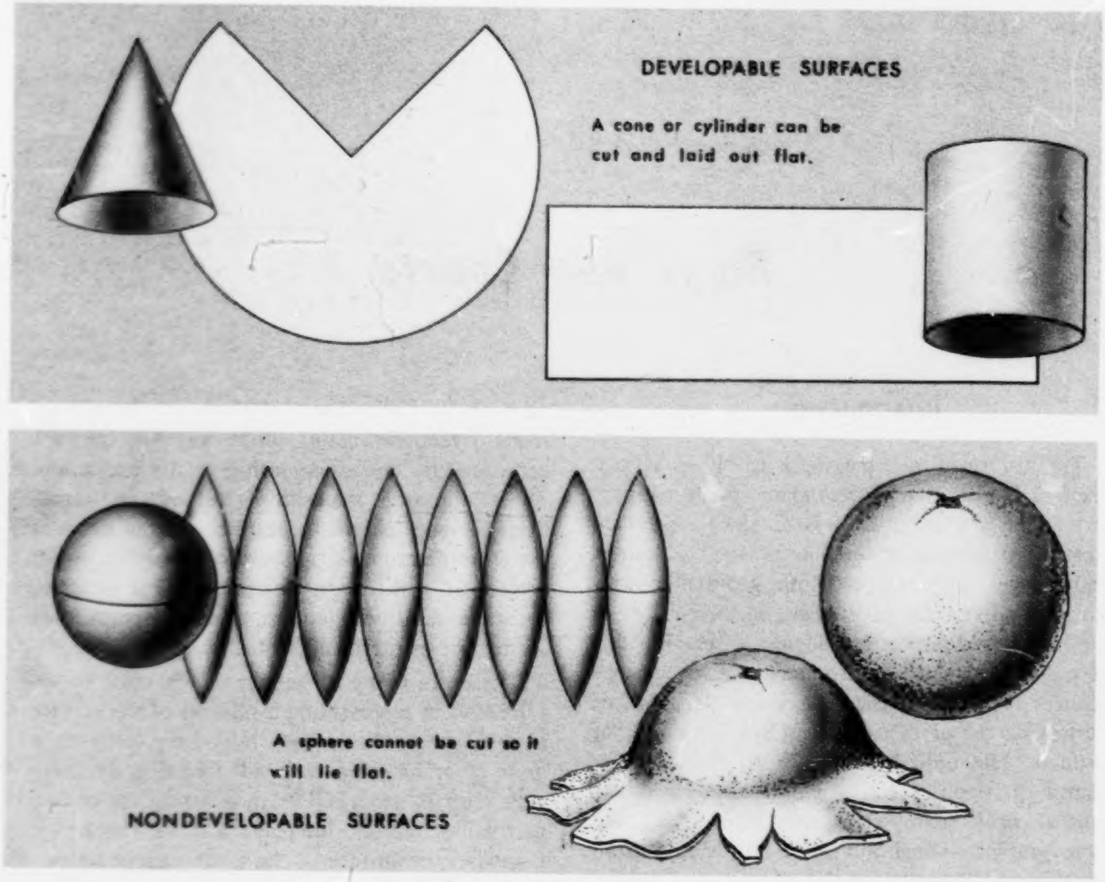

DEVELOPABLE SURFACES
A cone or cylinder can be cut and laid out flat.
A sphere cannot be cut so it will lie flat.
NONDEVELOPABLE SURFACES

Figure 3-1. Developable and Nondevelopable Surfaces

that cannot be formed into a plane without distortion are called nondevelopable. (See figure 3-1.)

- The problem of creating a projection lies in developing a method for transferring the meridians and parallels to the chart in a manner that will preserve certain desired characteristics as nearly as possible. The methods of projection are either mathematical or perspective.

The *perspective or geometric projection* consists of projecting a coordinate system based on the earth-sphere from a given point directly onto a developable surface. The properties and appearance of the resultant map will depend upon two factors: the type of developable surface and the position of the point of projection.

- The *mathematical projection* is derived analytically to provide certain properties or characteristics which cannot be arrived at geometrically. Some of these properties or characteristics are discussed under the heading, Choice of Projection.

While it is easier to visualize the various projections in relation to a particular developable surface, in actual practice the projections used by the U.S. Air Force are not projected upon a surface but are constructed according to certain mathematical principles.

Choice of Projection

Before considering how charts are made, consider what characteristics are desirable in a chart. The ideal chart projection would portray the features of the earth in their true relationship to each other; that is, directions would be true and distance would be represented at a constant scale over the entire chart. This would result in equality of area and true shape throughout the chart.

Such a relationship can only be represented on a globe. It is impossible to preserve, on a flat chart, constant scale and true direction in all directions at all points, nor can both relative size and shape of the geographic features be accurately portrayed throughout the chart. The characteristics most commonly desired in a chart projection are:

- Conformality
- Constant scale
- Equal area
- Great circles as straight lines
- Rhumb lines as straight lines
- True azimuth
- Geographic position easily located

CONFORMALITY. Of the many projection characteristics, conformality is the most important for air navigation charts. The single property of conformality most nearly fulfills the exacting requirements levied by Air Force needs. The limitations imposed by selection of this characteristic, with the resulting loss of other desirable but inharmonious qualities, are offset by the advantages of conformality. For any projection to be conformal, three conditions must be satisfied. These three conditions are used to advantage in air navigation.

1. First, the scale at any point on the projection must be independent of azimuth. This does not imply, however, that the scale about two points at different latitudes will be equal. It means, simply, that the scale at any given point will, for a short distance, be equal in all directions.

2. Second, the outline of areas on the chart must conform in shape to the feature being portrayed. This condition applies only to small and relatively small areas; large land masses must necessarily reflect any distortion inherent in the projection.

3. Finally, since the meridians and parallels of earth intersect at right angles, the longitude and latitude lines on all conformal projections must exhibit this same perpendicularity. This characteristic facilitates the plotting of points by geographic coordinates.

CONSTANT SCALE. The property of constant scale throughout the entire chart is highly desirable but impossible to obtain, as it would require that the scale be the same at all points and in all directions throughout the chart. This would mean that the plane surface of the chart could be fitted to the globe at all points by simply bending without any stretching or contraction, an obvious impossibility.

EQUAL AREA. These charts are so designed as to maintain a constant ratio of area throughout, although original shapes may be distorted beyond recognition. Where longitudinal dimensions are increased by distortion on equal area projections, there is a corresponding decrease in latitude sufficient to maintain the area ratio. In other words, where the scale along a meridian is increased, the scale along the corresponding parallel is proportionally decreased. Equal area charts are of little value to the navigator, since an equal area chart cannot be conformal. They are, however, often used for statistical purposes.

STRAIGHT LINE. The nature of the straight line on a map is equally as important as conformality. The rhumb line and the great circle are the two curves that a navigator might wish to have represented on a map as straight lines. A rhumb line is a line that crosses all successive meridians at a constant angle. Therefore an aircraft that maintains a constant course will track a rhumb line. The rhumb line is convenient to fly; however, the only projection which shows all rhumb lines as straight lines is the Mercator. A great circle is the shortest distance between any two points on the globe. An aircraft flying a constant heading using a directional gyro compensated for earth's rotation will track a great circle course. In high latitudes, the great circle is certainly the best curve to follow, but in equatorial regions there will be little difference in following either the rhumb line or the great circle. In intermediate latitudes, a choice may be made, but on a long flight, the saving obtained by flying a great circle should be given consideration. The only projection which shows all great circles as straight lines is the gnomonic projection. However, this is not a conformal projection and cannot be used directly for obtaining direction or distance. No conformal chart will even represent all great circles as straight lines.

TRUE AZIMUTH. It would be extremely desirable to have a projection which showed directions or azimuths as true throughout the chart. This would be particularly important to the navigator, who must determine from the chart the heading he will fly. There is no chart projection that will represent true great circle direction along a straight line from all points to all other points. This would require a conformal chart on which all great circles are represented as straight lines and such a chart does not exist. The azimuthal chart, however, will show true direction for a great circle, but only from the center point or the point of tangency of the chart.

Coordinates Easy to Locate. The geographic latitudes and longitudes of places should be easily found or plotted on the map when the latitudes and longitudes are known.

CLASSIFICATION OF PROJECTIONS

Chart projections may, of course, be classified in many ways. There is no way, however, that projections may be classified to be mutually exclusive. In this manual, the various projections are divided into three classes according to the type of developable surface to which the projections are related. Projections on these surfaces are termed azimuthal, cylindrical, and conical.

Azimuthal Projections

An azimuthal or zenithal projection is one in which points on the earth are transferred directly to a plane tangent to the earth. According to the positioning of the plane and the point of projection, various geometric projections may be derived. If the origin of the projecting rays (point of projection) is the center of the sphere, a gnomonic projection results. If it is located on the surface of the earth opposite the point of the tangent plane, the projection is a stereographic, and if it is at infinity, an orthographic projection results. Figure 3-2 shows these various points of projection.

Gnomonic Projection. All gnomonic projections are direct perspective projections. The graticule is projected from a source at the center of the sphere onto a plane surface tangent at any given point. Since the plane of every great circle cuts through the center of the sphere, the point of projection is in the plane of every great circle. The arc of any great circle, being in the plane of the great circle, will intersect another plane surface in a straight line. This property then becomes the most important and useful characteristic of the gnomonic projection. Each and every great circle is represented by a straight line on the projection.

Obviously a complete hemisphere cannot be projected onto this plane, since, for points 90° distant from the center of the map, the projecting lines are parallel to the plane of projection.

Because the gnomonic is nonconformal, shapes or land masses are distorted, and measured angles are not true. At only one point, the center of the projection, are the azimuths of lines true. At this point, the projection is said to be azimuthal.

Gnomonic projections are classified according to the point of tangency of the plane of projection. A gnomonic projection is polar gnomonic when

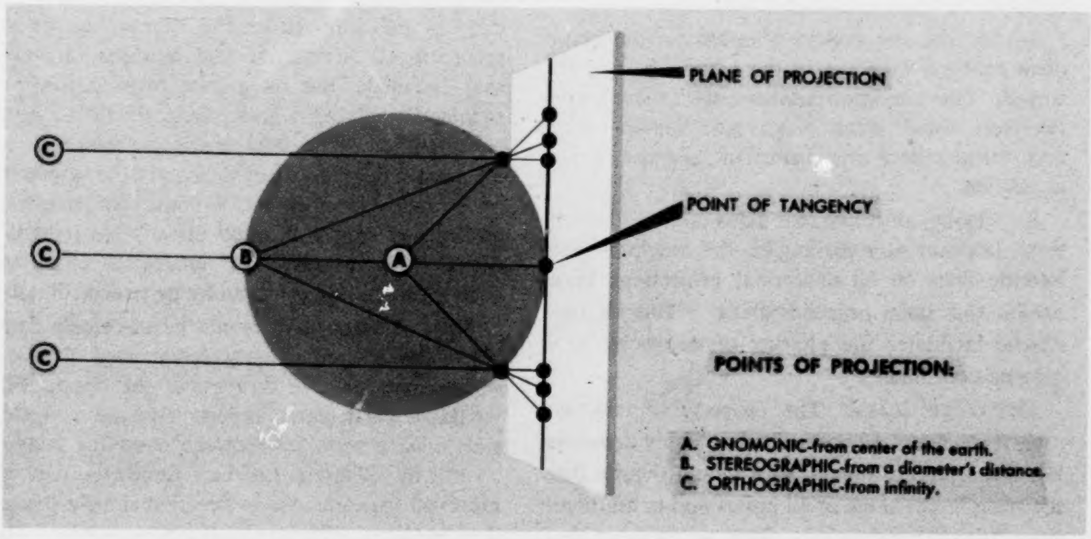

PLANE OF PROJECTION
POINT OF TANGENCY
C
C
C
B
A
POINTS OF PROJECTION:
A. GNOMONIC-from center of the earth.
B. STEREOGRAPHIC-from a diameter's distance.
C. ORTHOGRAPHIC-from infinity.

Figure 3-2. Azimuthal Projections

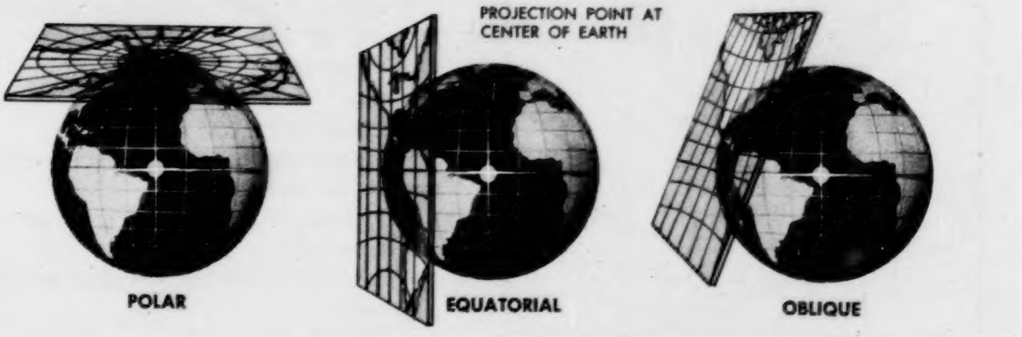


Figure 3-3. Gnomonic Projections

the point of tangency is one of the poles, equatorial gnomonic when the point of tangency is at the equator and any selected meridian, and oblique gnomonic when the point of tangency is at any point other than one of the poles or the equator. Figure 3-3 shows the plane of projection tangent to the earth at the pole, at the equator, and at a point of tangency other than one of the poles or the equator.

Polar Gnomonic. The meridians on a polar gnomonic, as on any polar projection, are radiating straight lines from the pole at true angles since the gnomonic is azimuthal at the center of the projection.

The parallels, as small circles on the sphere, are projected in concentric circles. An increasing area distortion occurs as the boundaries of the projection are approached. The equator cannot be projected, since the plane of the projection and the plane of equator are parallel. Although meridians and parallels intersect at right angles, the scale expansion along the parallels differs from rate of expansion along the meridians, therefore the polar gnomonic is not conformal.

The chart is used to determine great circle courses which are then transferred to a navigation plotting chart.

CHARACTERISTICS:

MERIDIANS: Straight lines radiating from the pole

PARALLELS: Concentric circles, distance apart increasing away from the pole

ANGLES: Angles between meridians and parallels: 90°

CONFORMALITY: Nonconformal

GREAT CIRCLES: Straight lines

RHUMB LINES: Spiral toward the pole

Figure 3-4 gives the appearance of the polar gnomonic.

Equatorial Gnomonic. The meridians on the equatorial gnomonic appear as parallel straight lines unequally spaced along and perpendicular to the equator.

The equator is also a straight line, while all other parallels are represented as hyperbolas. The equator will be an axis of symmetry for each hyperbola. The projection is also symmetrical about the central meridian (meridian of the point of tangency).

This chart is also used to determine the great

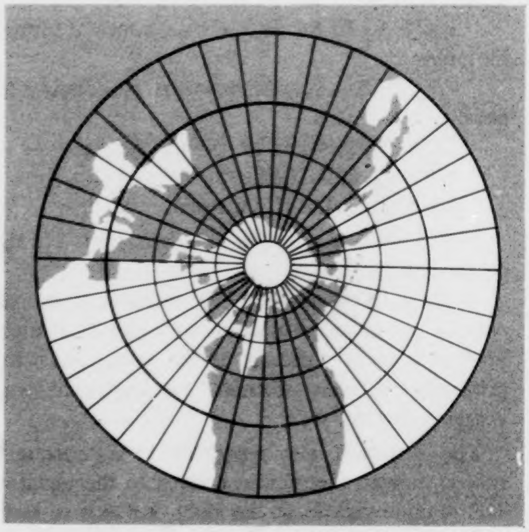


Figure 3-4. Polar Gnomonic Projection

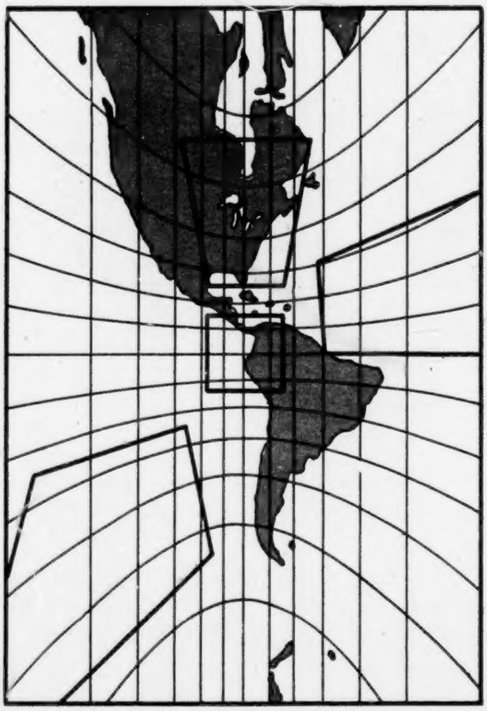


Figure 3-5. Equatorial Gnomonic Projection

circle course which can be transferred to an navigational plotting chart.

CHARACTERISTICS:

MERIDIANS: Parallel straight lines unequal distance apart

PARALLELS: Hyperbolas, concave toward the poles

ANGLES: Angles between meridians and parallels: Variable

CONFORMALITY: Nonconformal

GREAT CIRCLES: Straight lines

RHUMB LINES: Curved

Figure 3-5 gives the configuration of the equatorial gnomonic.

Oblique Gnomonic. The meridians on an oblique gnomonic projection converge in straight lines at a point representing the pole. Since the projection is nonconformal, the angles of convergence are not true.

The parallels are represented as unequally spaced, nonparallel curves convex to the equator. The oblique gnomonic has only one axis of symmetry, the central meridian passing through the center of the projection.

This chart is used by Direction Finding stations in laying off their radio bearings; it is primarily used for accurate tracking of aircraft by electronic devices.

CHARACTERISTICS:

MERIDIANS: Converging straight lines towards the pole

PARALLELS: Curved and concaved towards the pole

ANGLES: Between meridians and parallels: Variable

CONFORMALITY: Nonconformal

GREAT CIRCLES: Straight lines

RHUMB LINES: Curved

The oblique gnomonic projection is shown on figure 3-6.

STEREOGRAPHIC PROJECTION. The stereographic projection is a perspective conformal projection of the sphere. A projection based on a spheroidal surface is also a stereographic projection, having like characteristics except that it is

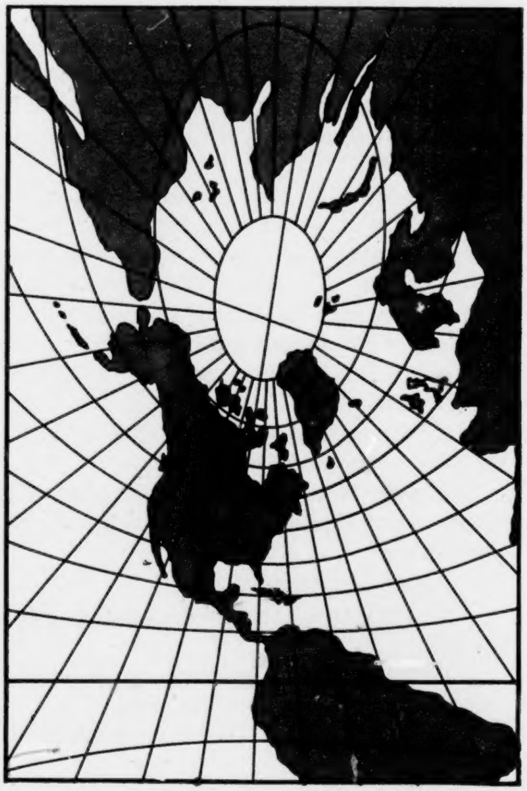


Figure 3-6. Oblique Gnomonic Projection

nonperspective. It is the only azimuthal projection which has no angular distortion and in which every circle within the area of the chart is projected as a circle. The stereographic projection is one in which the point of projection is placed on the surface at the end of the earth's diameter opposite the point of tangency.

The term horizon stereographic is applied to any stereographic projection where the center of the projection is positioned at any point other than the geographic poles or the equator. If the center is coincident with one of the poles of the reference surface, then the projection is called polar stereographic. If the center lies on the equator, then the primitive circle is a meridian, which gives the name meridian stereographic or equatorial stereographic. The illustration in figure 3-7 shows the three stereographic projections.

Horizon and Meridian Stereographic. Since the horizon stereographic and the meridian stereographic are not used in navigation, they are not discussed in this manual.

Polar Stereographic. The polar stereographic is the only stereographic projection where all the meridians are represented as straight lines. This is because all meridians pass through the projecting point. The meridians are not only represented as straight lines, but also as radiating from a point which is the center of the projection representing either the North or South Pole. The angles between meridians are true and are equal to the difference of their respective longitude values. The parallels are a series of concentric circles, their radial distances varying with the distance from the pole of the projection. Since the distance between parallels increases at the same rate as the circumference of the parallels, the scale will be the same along both the meridians and parallels at any one place.

The appearance of a great circle path on a projection is of special interest. In general, on a polar stereographic, the great circle path is an arc of a circle concave toward the pole. This is true for all great circles except meridians. The curvature of the great circle depends upon its distance from the center of projection. The closer a great circle path is to the center of the projection, the less is the curvature; i.e., the closer it is to the center of the projection, the more the curve approaches a straight line.

The great circle path represented on a stereographic projection is often stated as being approximately straight. This is true if the charted area of a stereographic projection is a small portion of a hemisphere or if the area considered is near the center of a projection. Thus the statement of a great circle path being approximately straight on a stereographic projection must be made with reservation.

CHARACTERISTICS:

MERIDIANS: Straight lines radiating from pole

PARALLELS: Concentric circles, distance apart increasing away from the pole

ANGLES: Between meridians and parallels: 90°

GREAT CIRCLE: Approximately straight near the poles, curved when not near the poles and concaved toward the pole

RHUMB LINE: Spirals toward the pole intersecting the meridians at a constant angle.

Although the rhumb line is of very little use on

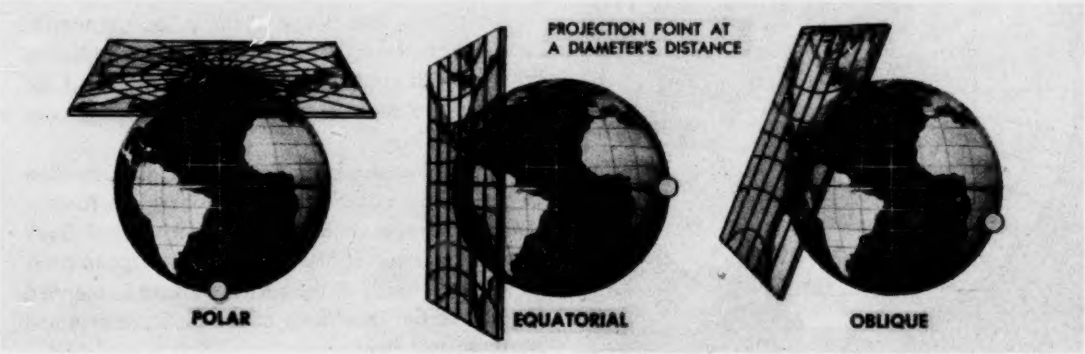


Figure 3-7. Stereographic Projections

a polar stereographic, it does present interesting sidelights and adds information to the characteristics of the projection. The rhumb line is shown as spiraling toward the pole, intersecting the meridians at a constant angle. The spiral approaches the pole more and more closely, never quite touching it. This constant angle on interesection is the same angle of intersection for the corresponding rhumb line on the surface of the earth. This is a further indication of the conformality of the projection.

The polar stereographic projection is illustrated in figure 3-8.

ORTHOGRAPHIC PROJECTION. An orthographic projection results when a light source at infinity projects the graticule of the reduced earth onto a plane tangent to the earth at some point perpendicular to the projecting rays. If the plane is tangent to the earth at the equator, the parallels appear as straight lines and the meridians as elliptical curves, except the meridian through the point of tangency, which is a straight line.

The illustration in figure 3-9 shows an equatorial orthographic projection. Its principal use in navigation is in the field of navigational astronomy, where it is useful for illustrating celestial coordinates, since the view of the moon, the sun, and other celestial bodies from the earth is essentially orthographic.

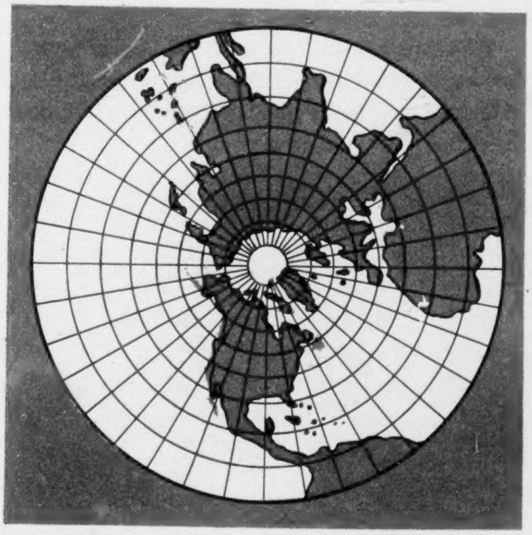


Figure 3-8. Polar Stereographic Projection

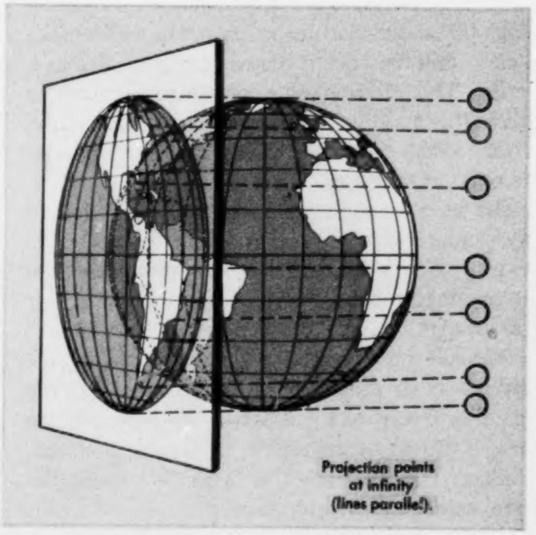


Figure 3-9. Equatorial Orthographic Projection

AZIMUTHAL EQUIDISTANT PROJECTION. This projection is neither perspective, equal area, nor conformal. It is called azimuthal equidistant because straight lines radiating from the center represent great circles as true azimuths and distances along these lines are true to scale.

The entire surface of the sphere is mapped in a circle, the diameter being equal to the circumference of the earth at reduced scale. With respect to the entire earth, the perimeter of the circle represents the points diametrically opposite the center of the projection. The appearance of the curves representing the parallels and meridians depends upon the point selected as the center of the projection and may be described in terms of three general classifications.

1. If the center is one of the poles, the meridians are represented as straight lines radiating from it, with convergence equal to unity, and the parallels are represented as equally spaced concentric circles.
2. If the center is on the equator, the meridian of the center point and its anti-meridian form a diameter of the circle (shown as a vertical line) and the equator is also a diameter perpendicular to it. One-fourth of the earth's surface is mapped in each of the quadrants of the circle determined by these two lines.
3. If the center is any other point, only the central meridian (and its anti-meridian) form a

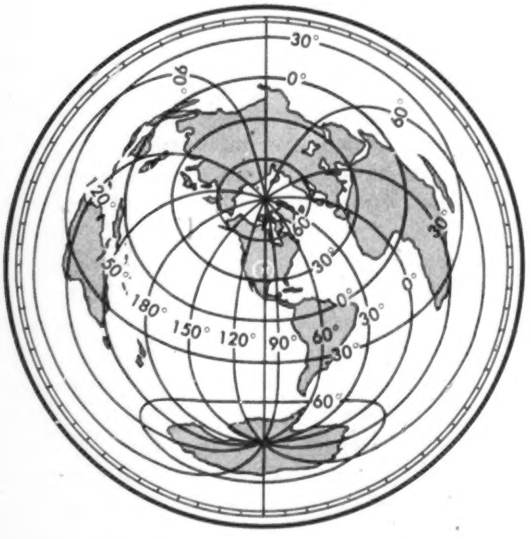


Figure 3-10. Azimuthal Equidistant Projection with Point of Tangency Lat. 40° N, Long. 100° W

straight line diameter. All other lines are curved. For an example of this projection, see figure 3-10.

The property of true distance and azimuth from the central point makes the projection useful in aeronautics and radio engineering. For example, if an important airport is selected for the point of tangency, the great circle distance and course from that point to any other position on the earth are quickly and accurately determined. Similarly, for communications work at a fixed point (point of tangency), the path of an incoming signal whose direction of arrival has been determined is at once apparent, as is the direction in which to train a directional antenna for desired results.

Cylindrical Projections

The only cylindrical projection used for navigation is the Mercator, named after its originator, Gerhard Mercator (Kramer), who first derived this type of chart in the year 1569. Before the time of this projection, mariners used a variety of charts, none of which satisfied the need for a conformal chart that depicted a rhumb line as a straight line. The Mercator is the only projection ever constructed that is conformal and at the same time displays the rhumb line as a straight line. The Mercator is probably the best known of all projections. It is used for navigation, for nearly all atlases (a word coined by Mercator), and for many wall maps.

Although copies of the original Mercator still exist, the exact method that was used in its construction is not known as Mercator himself did not indicate the method. For the sake of historical accuracy, it might be stated that his results were derived by approximate formula. The projection was further refined some years later when calculus was invented (about 1715), and better values were determined for the size of the earth.

Imagine a cylinder tangent to the equator, with the source of projection at the center of the earth. It would appear much like the illustration in figure 3-11, with the meridians being straight lines and the parallels being unequally spaced circles around the cylinder. It is obvious from the illustration that those parts of the terrestrial surface close to

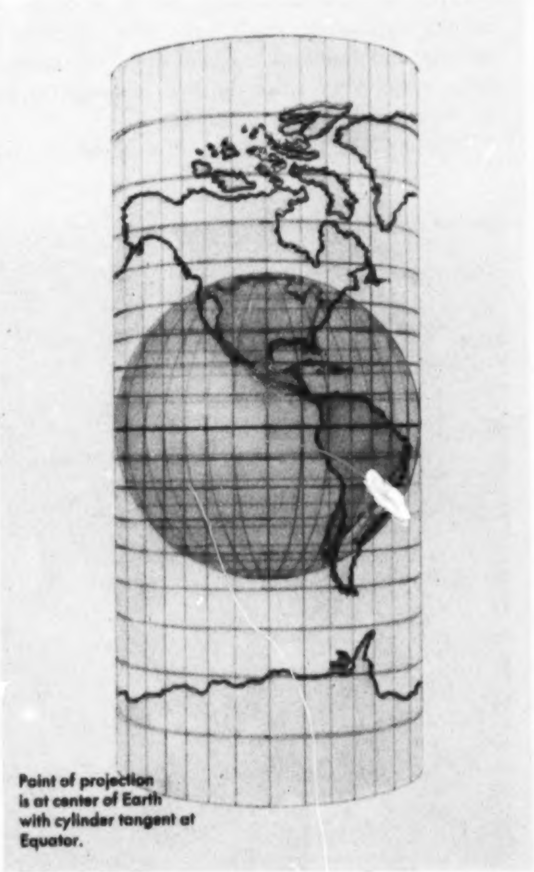


Figure 3-11. Cylindrical Projection

the poles could not be projected unless the cylinder were tremendously long, and that the poles could not be projected at all.

On the earth, the parallels of latitude are perpendicular to the meridians, forming circles of progressively smaller diameters as the latitude increases. On the cylinder, the parallels of latitude are shown perpendicular to the projected meridians, but since the diameter of a cylinder is the same at any point along the longitudinal axis, the projected parallels are all the same length. If the cylinder is cut along a vertical line—a meridian—and spread flat, the meridians appear as equal-spaced, vertical lines, and the parallels as horizontal lines.

The cylinder may be tangent at some great circle other than the equator, forming other types of cylindrical projections. If the cylinder is tangent at some meridian, it is a transverse cylindrical projection, and if it is tangent at any other point than the equator or a meridian, it is called an oblique cylindrical projection. The patterns of latitude and longitude appear quite different on these projections, since the line of tangency and the equator no longer coincide.

MERCATOR PROJECTION. The Mercator projection is a conformal, nonperspective projection; it is constructed by means of a mathematical transformation and cannot be obtained directly by graphical means. The distinguishing feature of the Mercator projection among cylindrical projections is that at any latitude the ratio of expansion of both meridians and parallels is the same, thus preserving the relationship existing on the earth. This expansion is equal to the secant of the latitude, with a small correction for the ellipticity of the earth. Since expansion is the same in all directions and since all directions and all angles are correctly represented, the projection is conformal. Rhumb lines appear as straight lines, and their directions can be measured directly on the chart. Distance can also be measured directly, but not by a single distance scale on the entire chart, unless the spread of latitude is small. Great circles appear as curved lines, concave to the equator, or convex to the nearest pole. The shapes of small areas are very nearly correct, but are of increased size unless they are near the equator as shown in figure 3-12.

CHARACTERISTICS: The Mercator has the following characteristics:

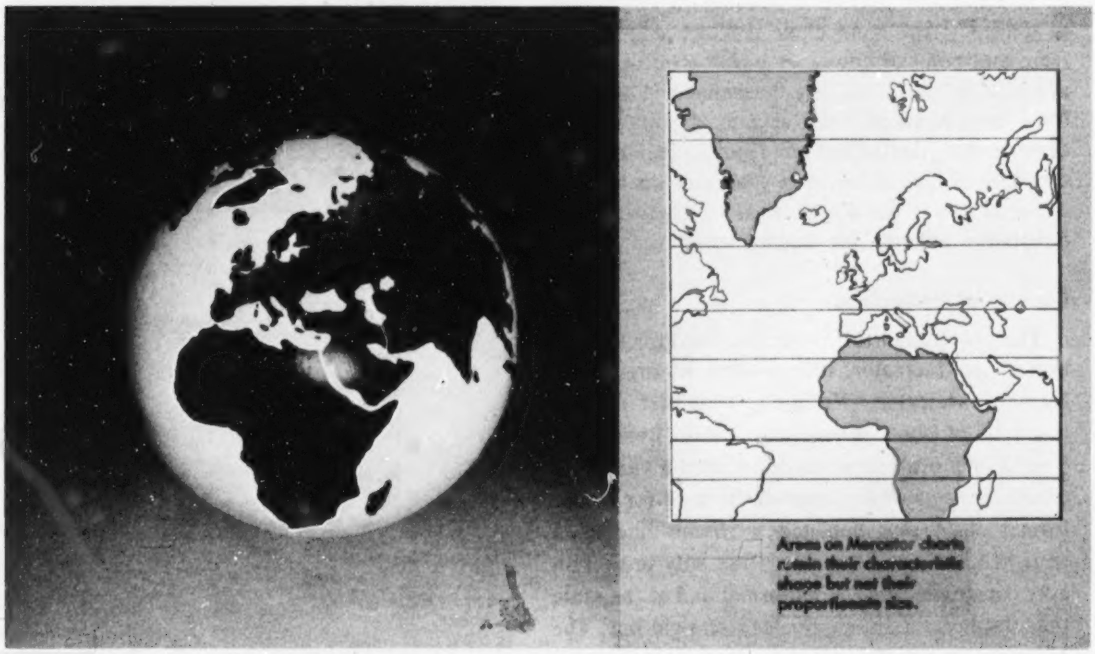

Areas on Mercator charts retain their characteristic shape but not their proportionate size.

Figure 3-12. Mercator is Conformal But Not Equal-Area

MERIDIANS: Straight, parallel lines, intersecting the parallels.

PARALLELS: Straight, parallel lines, at right angles.

SCALE: Correct only at the equator; elsewhere it expands as the secant of the latitude. Thus, the scale of a chart can apply only to a given latitude, and a variable scale is required to measure distances.

POLES: Because the secant of 90 degrees is infinity, the poles cannot be shown on the equatorial Mercator.

RHUMB LINE: Straight line.

GREAT CIRCLE: Curved line convex to the nearest pole.

CONFORMALITY: Projection is conformal and accordingly cannot be equal area. Areas are greatly exaggerated in high latitudes.

The Mercator projection has the following disadvantages:

- Difficulty of measuring large distances accurately.
- Conversion angle must be applied to great circle bearing before plotting.
- The chart is useless in polar regions above 80° N or S since the poles cannot be shown.

Transverse Mercator. The transverse or inverse Mercator is a conformal map designed for areas not covered by the equatorial Mercator. With the transverse Mercator, the property of straight meridians and parallels is lost, and the rhumb line is no longer represented by a straight line. The parallels and meridians become complex curves, and with geographic reference, the transverse Mercator is difficult to use as a plotting chart. The transverse Mercator, though often considered analogous to a projection onto a cylinder, is in reality a nonperspective projection that is constructed mathematically. This analogy (illustrated in figure 3-13) however, does permit the reader to visualize that the transverse Mercator will show scale correctly along the central meridian which forms the great circle of tangency. In effect, the cylinder has been turned 90 degrees from its position for the ordinary Mercator, and some meridian, called the central meridian, becomes the tangential great circle. One series of USAF charts using this type of projection places the cylinder tangent to the 90°E-90°W longitude.

These projections use a fictitious graticule similar to, but offset from, the familiar network of meridians and parallels. The tangent great circle is the fictitious equator. Ninety degrees from it are two fictitious poles. A group of great circles through these poles and perpendicular to the tangent constitutes the fictitious meridians, while a series of lines parallel to the plane of the tangent great circle forms the fictitious parallels.

On these projections, the fictitious graticule appears as the geographical one ordinarily appears on the equatorial Mercator. That is, the fictitious meridians and parallels are straight lines perpendicular to each other. The actual meridians and parallels appear as curved lines, except the line of tangency. Geographical coordinates are usually expressed in terms of the conventional graticule. A straight line on the transverse Mercator projection makes the same angle with all fictitious meridians, but not with the terrestrial meridians. It is therefore, a fictitious rhumb line.

The appearance of a transverse Mercator using the 90°E-90°W meridian as a reference or fictitious equator is shown in figure 3-13. The dotted lines are the lines of the fictitious projection. The N-S meridian through the center is the fictitious equator, and all other original meridians are now curves concave to the N-S meridian with the original parallels now being curves concave to the nearer pole.

CHARACTERISTICS:

MERIDIANS: The meridian of tangency and the two meridians 90 degrees removed from it are straight lines; all other meridians are curves concave to the tangent meridian.

PARALLELS: The equator is represented by a straight line; all other parallels are curves concave to the nearer pole. Meridians and parallels intersect at right angles.

SCALE: Scale is correct only along the tangent meridian; elsewhere, it is expanded. But at any point, scale expansion is the same in all directions.

GREAT CIRCLES: All lines perpendicular to the tangent meridian are great circles. Lines running parallel to the tangent meridian are small circles. Points 90 degrees from the tangent meridian cannot be projected.

CONFORMALITY: The projection is conformal, and accordingly cannot be equal-area.

Oblique Mercator. The cylindrical projection in which the cylinder is tangent at a great

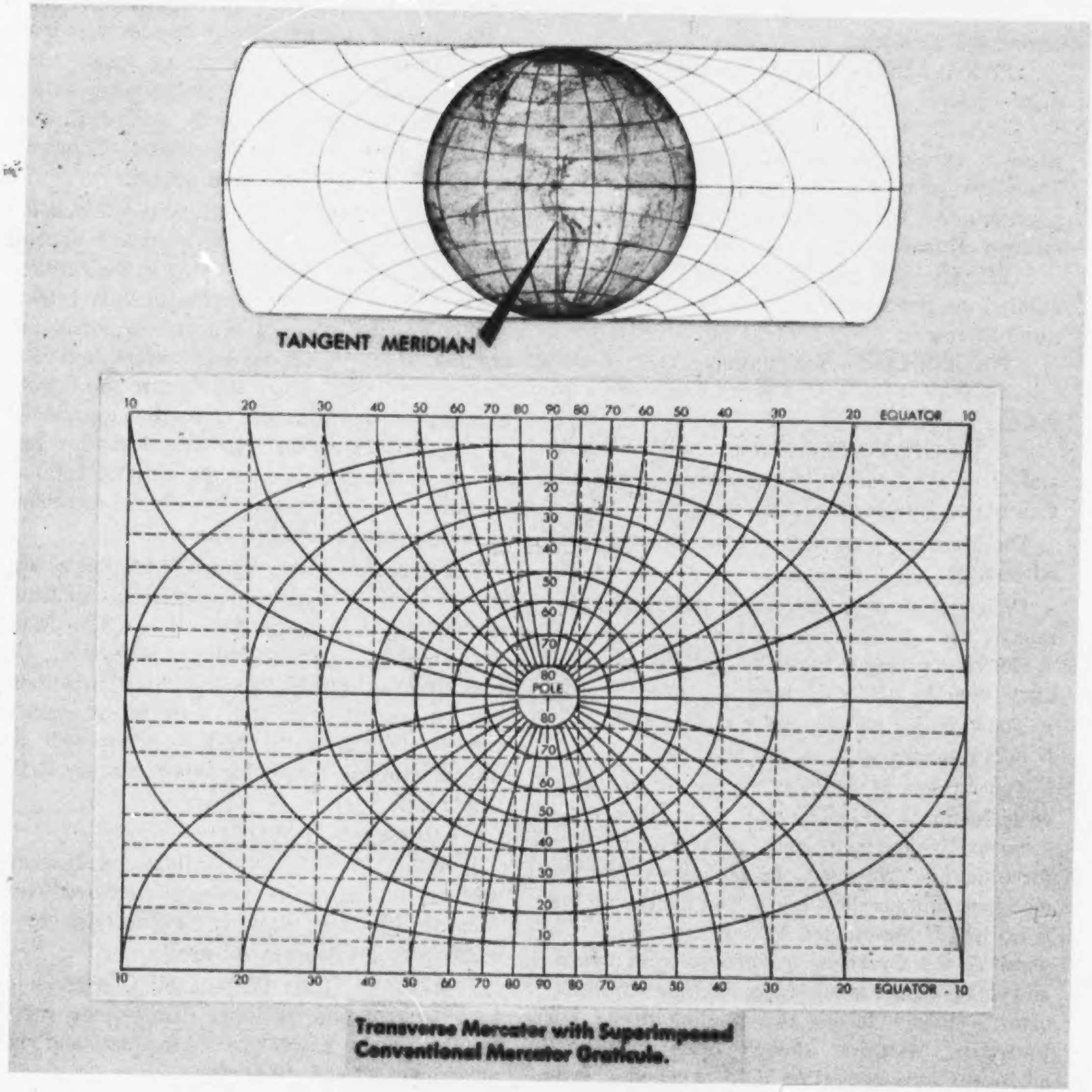

TANGENT MERIDIAN
10 20 30 40 50 60 70 80 90 80 70 60 50 40 30 20 EQUATOR 10
10 20 30 40 50 60 70 80 POLE 80 70 60 50 40 30 20 10
10 20 30 40 50 60 70 80 90 80 70 60 50 40 30 20 EQUATOR - 10
Transverse Mercator with Superimposed Conventional Mercator Graticule.

Figure 3-13. Transverse Cylindrical Projection—Cylinder Tangent at the Poles

circle other than the equator or a meridian is called an oblique Mercator (figure 3-14).

You can see that as a sphere fits into a cylinder, it makes no difference how it is turned. The fit, or line of tangency, can be any great circle. Thus, the Oblique Mercator projection is unique in that it is prepared and used for special purposes. This projection is used principally to depict an area in the near vicinity of an oblique great circle, as, for instance, along the great circle route between two important centers a relatively great distance apart (see figure 3-15).

Consider a flight between Seattle and Tokyo. The shortest distance is naturally the great circle distance and is, therefore, the route to fly. Plotting the great circle on a Mercator, you find that it takes the form of a high arching curve as shown. Since the scale on a Mercator changes with latitude, there will be a considerable scale change

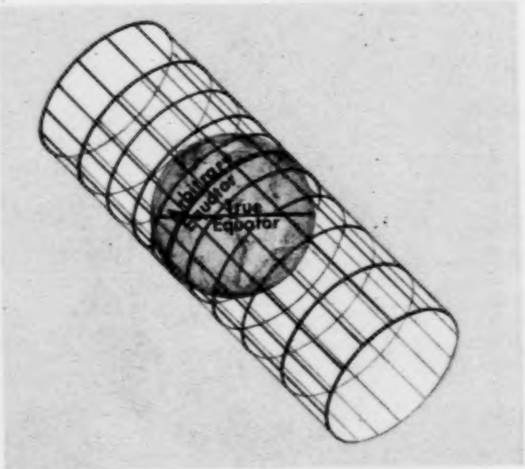


Figure 3-14. Oblique Mercator Projection

when you consider the latitude band that this great circle route covers.

If you were only concerned with the great circle route and a small band of latitude (say 5°) on either side, the answer to your problem would be the Oblique Mercator. With the cylinder made tangential along the great circle joining Seattle and Tokyo, the resultant graticule would enjoy most of the good properties found near the equator on a conventional Mercator.

Advantages. The Oblique Mercator projection has several desirable properties. The projection is conformal. The x axis is a great circle course at true scale. The projection can be constructed using any desired great circle as the x axis. The scale is equal to the secant of the angular distance from the x axis. Therefore, near the x axis the scale change is slight. This makes the projection almost ideal for strip charts of great-circle flights.

Limitations. The projection also has many disadvantages. Rhumb lines are curved lines, therefore, the chart is of little use to the navigator. Scale expansion and area distortion in the region of the oblique pole are the same as that of the standard Mercator in the region of the pole. Radio bearings cannot be plotted directly on the chart. All meridians and parallels are curved lines. A separate projection must be computed and constructed for each required great circle course.

Conic Projections

There are two classes of conic projections. The first is a simple conic projection constructed by placing the apex of the cone over some part of the earth (usually the pole) with the cone tangent to a parallel called the standard parallel and project-

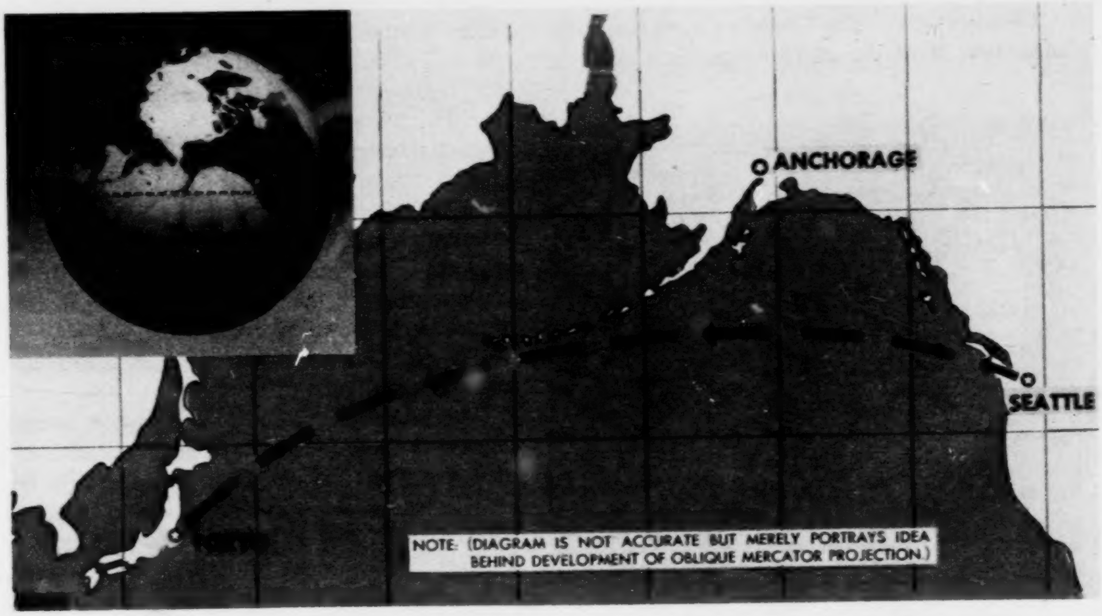

ANCHORAGE
SEATTLE
NOTE: (DIAGRAM IS NOT ACCURATE BUT MERELY PORTRAYS IDEA BEHIND DEVELOPMENT OF OBLIQUE MERCATOR PROJECTION.)

Figure 3-15. Great Circle Route from Seattle to Tokyo on Mercator Projection

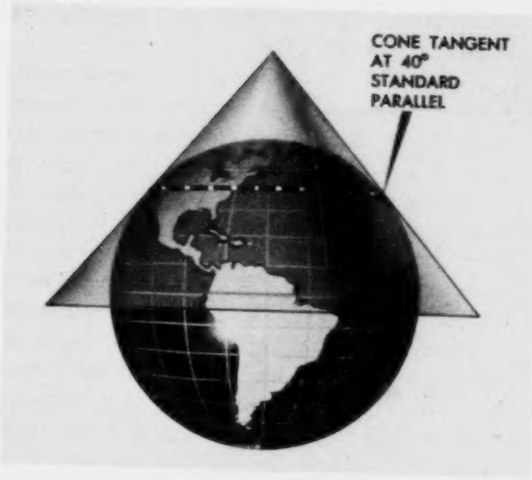


Figure 3-16. Simple Conic Projection

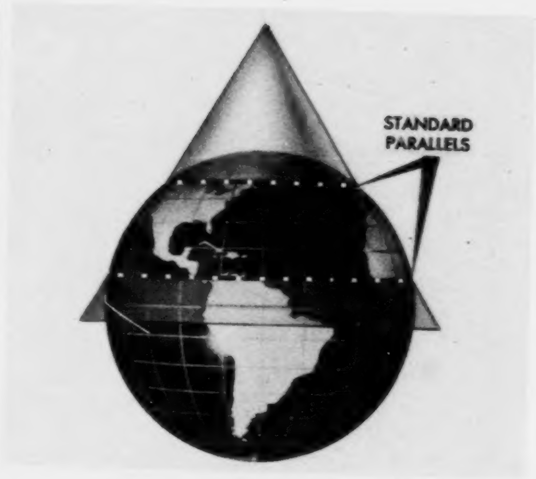


Figure 3-18. Conic Projection Using Secant Cone

ing the graticule of the reduced earth onto the cone as shown in figure 3-16. The chart is obtained by cutting the cone along some meridian and unrolling it to form a flat surface. Notice in figure 3-17, the characteristic gap that appears when the cone is unrolled. The second is a secant cone, cutting through the earth and actually contacting the surface at two standard parallels as shown in figure 3-18.

LAMBERT CONFORMAL (Secant Cone).

Characteristics. The Lambert Conformal conic projection is of the conical type in which the meridians are straight lines which meet at a common point beyond the limits of the chart and parallels are concentric circles, the center of which is the point of intersection of the meridians. Meridians and parallels intersect at right angles. Angles formed by any two lines or curves on the earth's surface are correctly represented.

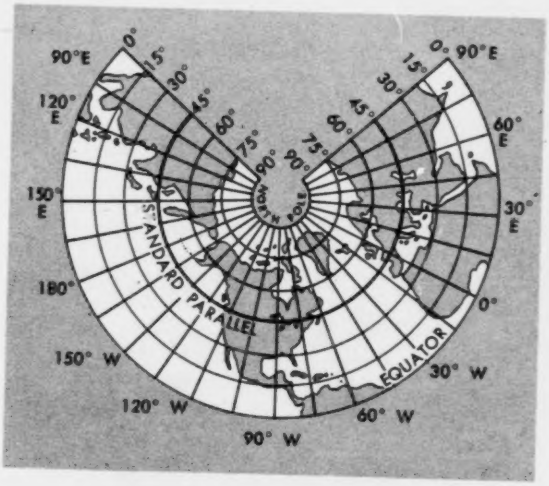


Figure 3-17. Simple Conic Projection of Northern Hemisphere

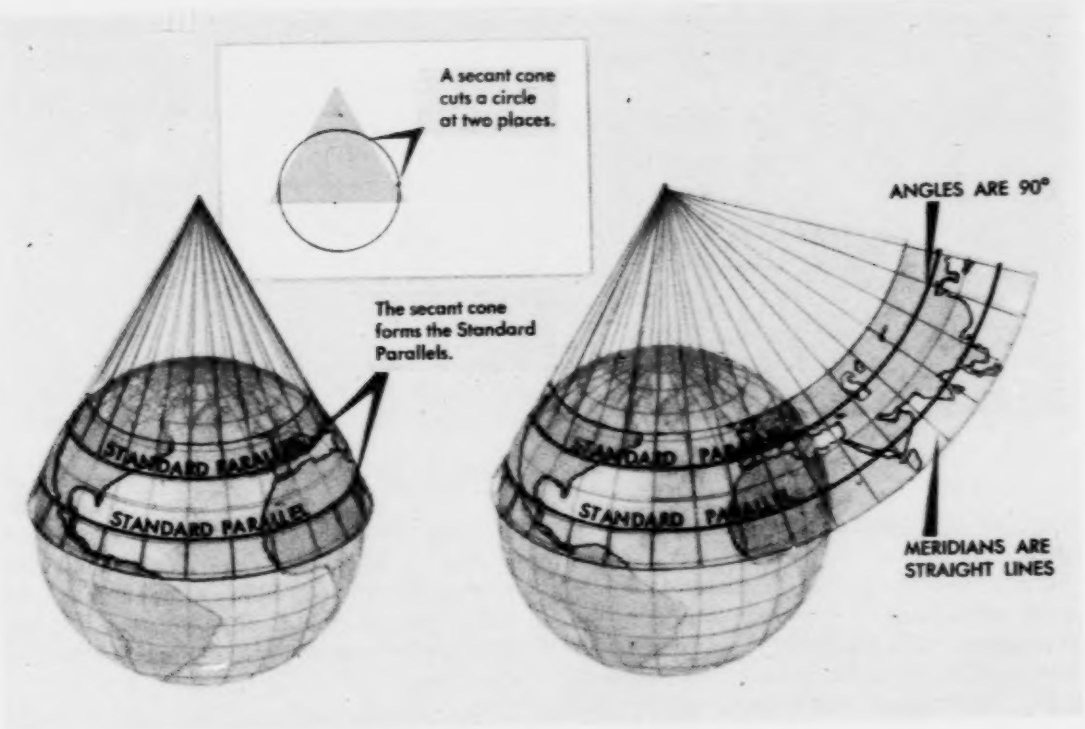
The projection may be developed by either the graphic or mathematical method. It employs a secant cone intersecting the spheroid at two parallels of latitude, called the standard parallels, of the area to be represented. The standard parallels are represented at exact scale. Between these parallels the scale factor is less than unity and beyond them greater than unity. For equal distribution of scale error (within and beyond the standard parallels) the standard parallels are selected at one-sixth and five-sixths of the total length of the segment of the central meridian represented. The development of the Lambert Conformal conic projection is shown by figure 3-19.

The great elliptic is a curve closely approximating a straight line.

The geodesic is a curved line always concave toward the mid-parallel, except in the case of a meridian where, by definition, it is a straight line.

The loxodrome, with the exception of meridians, is a curved line concave toward the pole.

Uses. The chief use of the Lambert Conformal conic projection is in mapping areas of small latitudinal width but great longitudinal extent. No projection can be both conformal and equal area,


A secant cone cuts a circle at two places.

The secant cone forms the Standard Parallels.

Figure 3.19. Lambert Conformal Conic Projection

but by limiting latitudinal width, scale error is decreased to the extent that the projection gives very nearly an equal area representation in addition to the inherent quality of conformality. This makes the projection very useful for aeronautical charts.

Advantages. Some of the chief advantages of the Lambert Conformal conic projection are:

- Conformality
- Great circles are approximated by straight lines (actually concave toward the mid-parallel).
- For areas of small latitudinal width, scale is nearly constant. For example, the U.S. may be mapped with standard parallels 33°N and 45°N with a scale error of only 2½% for southern Florida. The maximum scale error between 30° 30′N and 47°30′N is only one-half of 1%.
- Positions are easily plotted and read in terms of latitude and longitude.
- Construction is relatively simple.
- Its two standard parallels give it two "lines of strength" (lines along which elements are represented true to shape and scale).
- Distances may be measured quite accurately. For example the distance from Pittsburgh to Constantinople is 5,277 statute miles; distance as measured by the graphic scale on a Lambert projection (standard parallels 36°N and 54°N) without application of the scale factor is 5,258 statute miles, an error of less than four-tenths of 1%.

Limitations. Some of the chief limitations of the Lambert Conformal Conic projection are:

- Rhumb lines are curved lines which cannot be plotted accurately.
- Great circles are curved lines concave toward the mid-parallel.
- Maximum scale increases as latitudinal width increases.
- Parallels are curved lines (arcs of concentric circles).
- Continuity of conformality ceases at the junction of two bands, even though each is conformal. If both have the same scale along their standard parallels, the common parallel (junction) will have a different radius for each band, therefore they will not join perfectly.

CONSTANT OF THE CONE. Most conic charts have the constant of the cone (convergence factor)

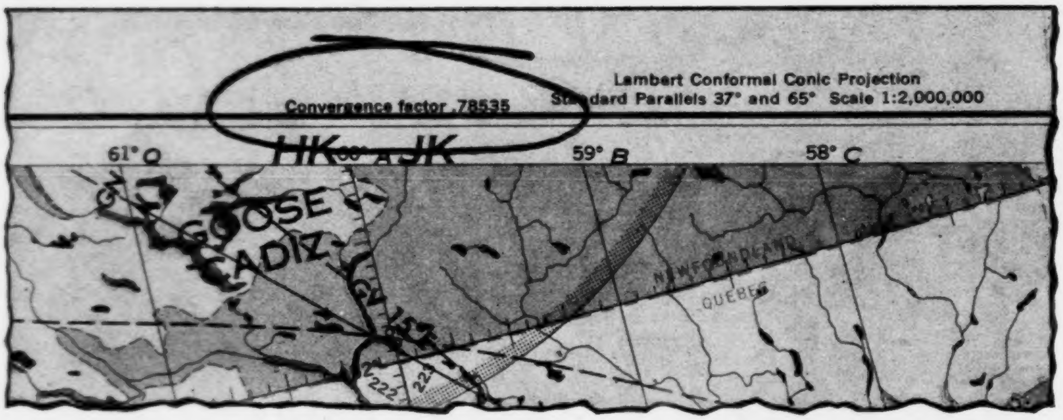

Lambert Conformal Conic Projection
Standard Parallels 37° and 65° Scale 1:2,000,000
Convergence factor .78535
61° O
HK 60° A JK
59° B
58° C
GOOSE
CADIZ
NEWFOUNDLAND
QUEBEC
GN 152
222
221

Figure 3-20. Convergence Factor on JN Chart

computed and listed on the chart as shown in figure 3-20.

Convergence Angle. The convergence angle is the actual angle on a chart formed by the intersection of the Greenwich meridian and some other meridian; the pole serves as the vertex of the angle. Convergence angles, like longitudes, are measured east and west from the Greenwich meridian.

Convergence Factor. A chart's convergence factor is a decimal number which expresses the ratio between meridional convergence as it actually exists on the earth and as it is portrayed on the chart. When the convergence angle equals the number of the selected meridian, the chart convergence factor is 1.0. When the convergence angle is less than the number of the selected meridian, the chart convergence factor is proportionately less than 1.0.

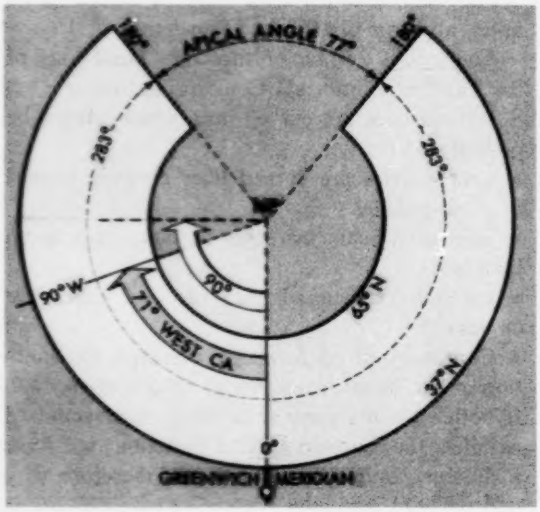

APICAL ANGLE 77°
180°
180°
283°
283°
NP
90°W
90°
71° WEST CA
65°N
37°N
0°
GREENWICH MERIDIAN

Figure 3-21. A Lambert Conformal, Convergence Factor 0.785

The subpolar projection illustrated in figure 3-21 portrays the standard parallels, 37°N and 65°N. It presents 360 degrees of the earth's surface on 283 degrees of paper. Therefore, the chart has a convergence factor (CF) of 0.785 (283 degrees divided by 360 degrees equals 0.785). Meridian 90°W forms a west convergence angle (CA) of 71° with the Greenwich meridian. Expressed as a formula:

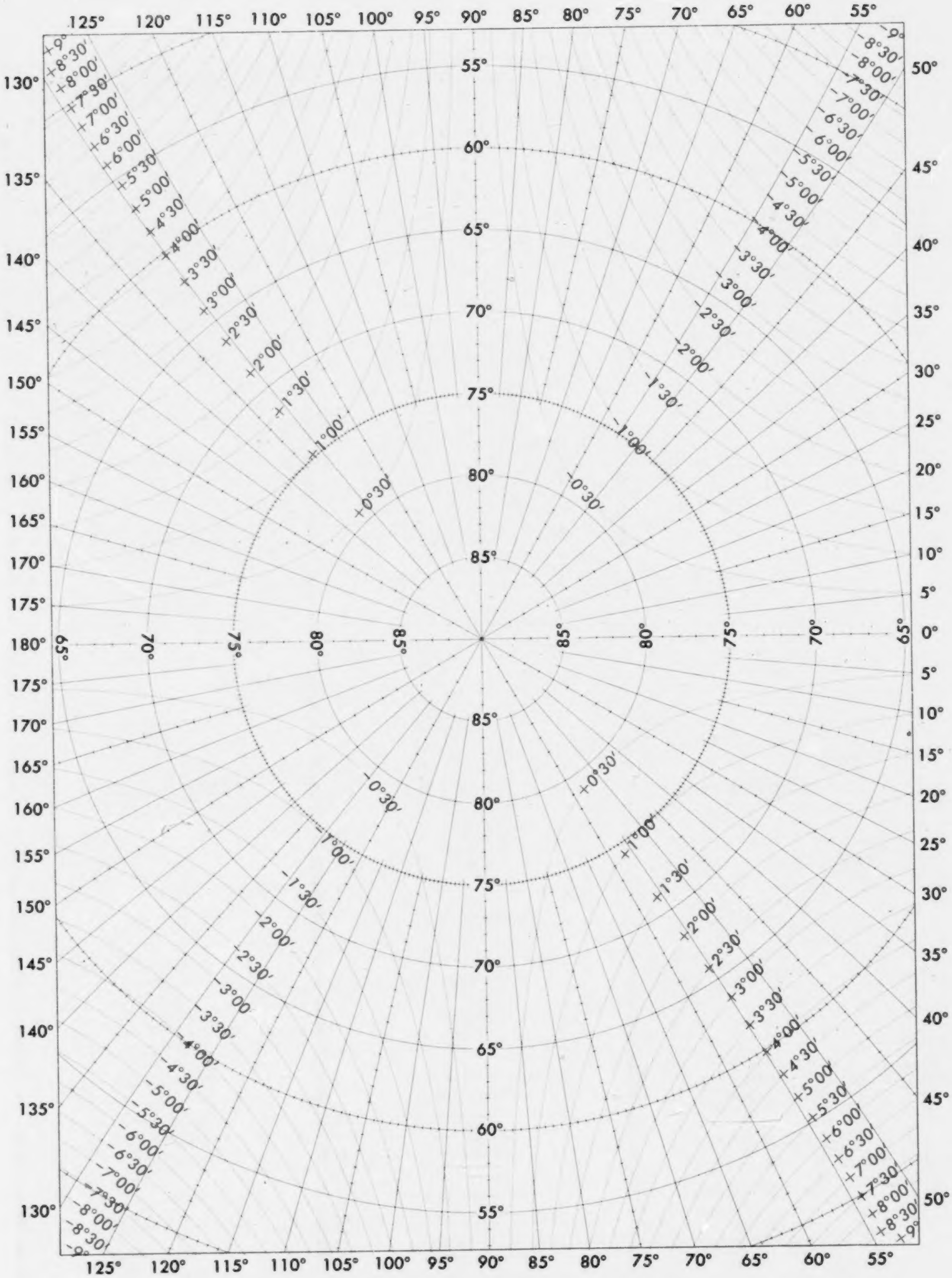
CF × longitude = CA

0.785 × 90°W = 71° west CA

A chart's convergence factor is easily approximated on subpolar charts by:

1. Drawing a straight line which covers 10 lines of longitude.
2. Measuring the true course at each end of the line, noting the difference between them, and dividing the difference by 10.
3. The quotient represents the chart's convergence factor.

Because of its projection, the meridians on a Transverse Mercator chart do not coincide with the meridians on the earth. As a result, the meridians appear as curved lines on the chart. A correction factor is obtained through the use of a graph (figure 3-22) to mathematically straighten the longitudes.



To obtain the convergence factor required for determination of heading information:

A. Place pencil point on geographic location for which heading information is to be determined.

B. Note correction factor lines indicating ½ degree interval of correction annotated in green.

C. Interpret correction factor to closest ¼ degree.

D. Grid Heading equals True Heading + W. longitude ± correction factor.
Grid Heading equals True Heading − E. longitude ∓ correction factor.

Figure 3-22. Transverse Mercator Convergence Graph

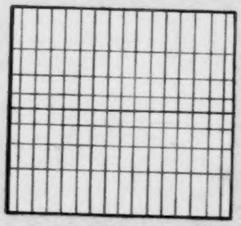
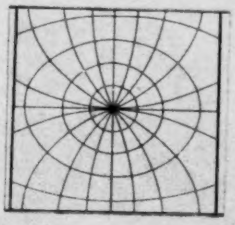
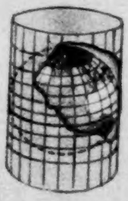
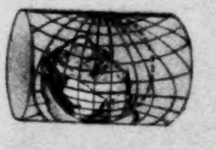
		MERCATOR	TRANSVERSE MERCATOR
CHARACTERISTICS OF THE PROJECTION	CONFORMALITY	CONFORMAL	CONFORMAL
	DISTANCE SCALE	VARIABLE (Measure at Mid-Latitude)	NEARLY CONSTANT (Near Meridian of true scale)
	DISTORTION OF SHAPES & AREAS	INCREASES AWAY FROM EQUATOR	INCREASES AWAY FROM TANGENT MERIDIAN
	ANGLE BETWEEN PARALLELS AND MERIDIANS	90° ANGLE	90° ANGLE
	APPEARANCE OF PARALLELS	PARALLEL STRAIGHT LINES UNEQUALLY SPACED	CURVES CONCAVE TOWARD NEAREST POLE
	APPEARANCE OF MERIDIANS	PARALLEL STRAIGHT LINES EQUALLY SPACED	COMPLEX CURVES CONCAVE TOWARD CENTRAL MERIDIAN
	APPEARANCE OF PROJECTION		
	GRAPHIC ILLUSTRATION		
PRODUCTION	METHOD OF PRODUCTION	MATHEMATICAL	MATHEMATICAL
	ORIGIN OF PROJECTORS	FROM CENTER OF SPHERE (For illustration only)	FROM CENTER OF SPHERE (For illustration only)
	POINT OF TANGENCY	EQUATOR	GREAT CIRCLE THROUGH THE POLES
APPEARANCE OF LINES ON CHARTS	STRAIGHT LINE CROSSES MERIDIANS	CONSTANT ANGLE (Rhumb line)	VARIABLE ANGLE (Approximates Great Circle)
	GREAT CIRCLE	CURVED LINE (Except Equator and Meridians)	APPROXIMATED BY STRAIGHT LINE
	RHUMB LINE	STRAIGHT LINE	CURVED LINE
	NAVIGATIONAL USES	DEAD RECKONING AND CELESTIAL (Suitable for all types)	GRID NAVIGATION IN POLAR AREAS

Figure 3-23. Cylindrical Projections

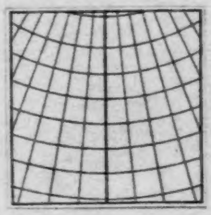
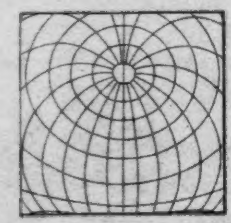
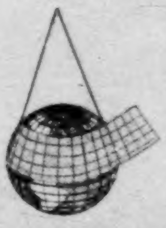
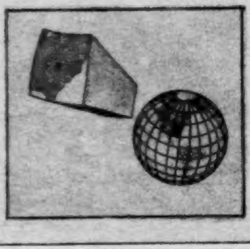
		LAMBERT CONFORMAL	AZIMUTHAL EQUIDISTANT
CHARACTERISTICS OF THE PROJECTION	CONFORMALITY	CONFORMAL	NOT CONFORMAL
	DISTANCE SCALE	NEARLY CONSTANT	CORRECT SCALE AT ALL AZIMUTHS FROM CENTER ONLY
	DISTORTION OF SHAPES & AREAS	VERY LITTLE	INCREASES AWAY FROM CENTER
	ANGLE BETWEEN PARALLELS AND MERIDIANS	90° ANGLE	VARIABLE ANGLE
	APPEARANCE OF PARALLELS	ARCS OF CONCENTRIC CIRCLES NEARLY EQUALLY SPACED	CURVED LINES UNEQUALLY SPACED
	APPEARANCE OF MERIDIANS	STRAIGHT LINES CONVERGING AT THE POLE	CURVED LINES CONVERGING AT THE POLE
	APPEARANCE OF PROJECTION		
	GRAPHIC ILLUSTRATION		
PRODUCTION	METHOD OF PRODUCTION	MATHEMATICAL	MATHEMATICAL
	ORIGIN OF PROJECTORS	FROM CENTER OF SPHERE (For illustration only)	NOT PROJECTED
	POINT OF TANGENCY	TWO STANDARD PARALLELS	NONE
APPEARANCE OF LINES ON CHARTS	STRAIGHT LINE CROSSES MERIDIANS	VARIABLE ANGLE (Approximates Great Circle)	VARIABLE ANGLE
	GREAT CIRCLE	APPROXIMATED BY STRAIGHT LINE	ANY STRAIGHT LINE RADIATING FROM CENTER OF PROJECTION
	RHUMB LINE	CURVED LINE	CURVED LINE
	NAVIGATIONAL USES	PILOTAGE AND RADIO (Suitable for all types)	AERONAUTICS/RADIO ENGINEERING & CELESTIAL MAP

Figure 3-24. Conic Projection *Not Projected*

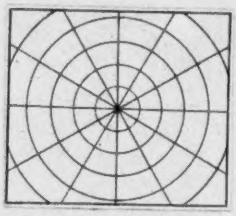
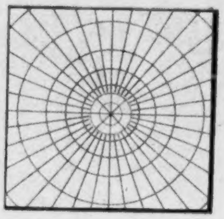
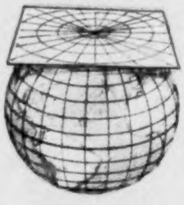
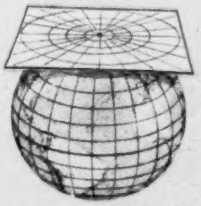
		POLAR STEREOGRAPHIC	POLAR GNOMONIC
CHARACTERISTICS OF THE PROJECTION	CONFORMALITY	CONFORMAL	NOT CONFORMAL
	DISTANCE SCALE	NEARLY CONSTANT EXCEPT ON SMALL SCALE CHARTS	VARIABLE
	DISTORTION OF SHAPES & AREAS	INCREASES AWAY FROM POLE	INCREASES AWAY FROM POLE
	ANGLE BETWEEN PARALLELS AND MERIDIANS	90° ANGLE	90° ANGLE
	APPEARANCE OF PARALLELS	CONCENTRIC CIRCLES UNEQUALLY SPACED	CONCENTRIC CIRCLES UNEQUALLY SPACED
	APPEARANCE OF MERIDIANS	STRAIGHT LINES RADIATING FROM THE POLE	STRAIGHT LINES RADIATING FROM THE POLE
	APPEARANCE OF PROJECTION		
	GRAPHIC ILLUSTRATION		
PRODUCTION	METHOD OF PRODUCTION	GRAPHIC OR MATHEMATICAL	GRAPHIC OR MATHEMATICAL
	ORIGIN OF PROJECTORS	FROM OPPOSITE POLE	FROM CENTER OF SPHERE
	POINT OF TANGENCY	POLE	POLE
APPEARANCE OF LINES ON CHARTS	STRAIGHT LINE CROSSES MERIDIANS	VARIABLE ANGLE (Approximates Great Circle)	VARIABLE ANGLE (Great Circle)
	GREAT CIRCLE	APPROXIMATED BY STRAIGHT LINE	STRAIGHT LINE
	RHUMB LINE	CURVED LINE	CURVED LINE
	NAVIGATIONAL USES	ALL TYPES OF POLAR NAVIGATION	GREAT CIRCLE NAVIGATION AND PLANNING

Figure 3-25. Azimuth Projections

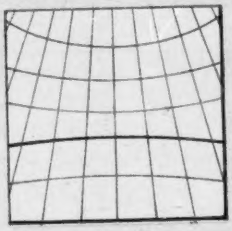
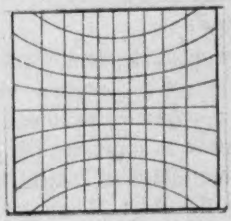
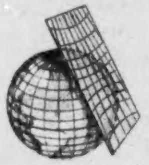
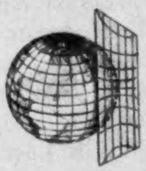
		OBLIQUE GNOMONIC	EQUATORIAL GNOMONIC
CHARACTERISTICS OF THE PROJECTION	CONFORMALITY	NOT CONFORMAL	NOT CONFORMAL
	DISTANCE SCALE	VARIABLE	VARIABLE
	DISTORTION OF SHAPES & AREAS	INCREASES AWAY FROM POINT OF TANGENCY	INCREASES AWAY FROM CENTER OF PROJECTION
	ANGLE BETWEEN PARALLELS AND MERIDIANS	VARIABLE ANGLE	VARIABLE ANGLE
	APPEARANCE OF PARALLELS	CURVED LINES UNEQUALLY SPACED	CURVED LINES UNEQUALLY SPACED
	APPEARANCE OF MERIDIANS	STRAIGHT LINES CONVERGING AT THE POLE	STRAIGHT PARALLEL LINES UNEQUALLY SPACED
	APPEARANCE OF PROJECTION		
	GRAPHIC ILLUSTRATION		
PRODUCTION	METHOD OF PRODUCTION	GRAPHIC OR MATHEMATICAL	GRAPHIC OR MATHEMATICAL
	ORIGIN OF PROJECTORS	FROM CENTER OF SPHERE	FROM CENTER OF SPHERE
	POINT OF TANGENCY	VARIABLE	EQUATOR (Meridian variable)
APPEARANCE OF LINES ON CHARTS	STRAIGHT LINE CROSSES MERIDIANS	VARIABLE ANGLE (Great Circle)	CONSTANT ANGLE (Great Circle)
	GREAT CIRCLE	STRAIGHT LINE	STRAIGHT LINE
	RHUMB LINE	CURVED LINE	CURVED LINE
	NAVIGATIONAL USES	GREAT CIRCLE NAVIGATION AND PLANNING	GREAT CIRCLE NAVIGATION AND PLANNING

Figure 3-25. Azimuthal Projections (continued)

AERONAUTICAL CHARTS

An aeronautical chart is a pictorial representation of a portion of the earth's surface upon which lines and symbols in a variety of colors represent features and/or details that can be seen on the earth's surface. In addition to ground image, many additional symbols and notes are added to indicate navigation aids and data necessary for air navigation. Properly used, a chart is a vital adjunct to navigation; improperly used, it may even prove a hazard. Without it, modern navigation would never have reached its present state of development. Because of their great importance, the navigator must be thoroughly familiar with the wide variety of aeronautical charts and understand their many uses.

Aeronautical charts are produced on many different types of projections. A projection can be defined as a systematic construction of lines on a plane surface to represent the parallels of latitude and the meridians of longitude of the earth or a section of the earth. These projections may range from the Equatorial Mercator for a Loran chart to the Transverse Mercator for the polar region. Since the demand for variety in charts is so great and since the properties of the projections vary greatly, there is no one projection that will satisfy all the needs of contemporary navigation. The projection that most nearly answers all the navigator's problems is the Lambert Conformal, and this projection is the one most widely used for aeronautical charts.

Aeronautical Charts, in their full range of projections, give worldwide coverage. Some single projections used for a single series of charts will cover nearly all the earth. An aeronautical chart of some projection and scale can be obtained for any portion of the earth. The accuracy of the information displayed on these charts will vary, but generally speaking, world-wide aeronautical charts in use today are very accurate representations of the earth's surface.

Scale

Obviously, charts are much smaller than the area which they represent. The ratio between any given unit of length on a chart and the true distance it represents on the earth is the scale of the chart. The scale may be relatively uniform over the whole chart, or it may vary greatly from one part of the chart to another. Charts are made to various scales for different purposes. If a chart is to show the whole world and yet not be too large, it must be drawn to small scale. If a chart is to show much detail, it must be drawn to a large scale; then it shows a smaller area than does a chart of the same size drawn to a small scale. Remember: large area, small scale; small area, large scale.

The scale of a chart may be given by a simple statement, such as, "one inch equals ten miles." This, of course, means that a distance of ten miles on the earth's surface is shown one inch long on the chart. On aeronautical charts the scale is indicated in one of two ways, representative fraction or graphic scale.

Representative Fraction. The scale may be given as a representative fraction, such as 1:500,000 or 1/500,000. This means that one of any unit on the chart represents 500,000 of the same unit on the earth. For example, one inch on the chart represents 500,000 of the same unit on the earth.

A representative fraction can be converted into a statement of miles to the inch. Thus, if the scale is 1:1,000,000, one inch on the chart stands for 1,000,000 inches or 1,000,000 divided by (6080 × 12) equals about 13.7 NM. Similarly, if the scale is 1:500,000, one inch on the chart represents about 6.85 NM. Thus, the larger the denominator of the representative fraction, the smaller the scale.

Graphic Scale. The graphic scale may be shown by a graduated line. It usually is found printed along the border of a chart. Take a measurement on the chart and compare it with the graphic scale of miles. The number of miles that the measurement represents on the earth may be read directly from the graphic scale on the chart.

The distance between parallels of latitude also provides a convenient scale for distance measurement. As shown in figure 3-26, one degree of latitude always equals sixty nautical miles and one minute of latitude equals one nautical mile.

DOD Aeronautical Charts and Flight Information Publications

The following publications are available to pilots and navigators in base operations offices, flight planning rooms, and other locations where aeronautical charts are issued or where flight planning takes place.

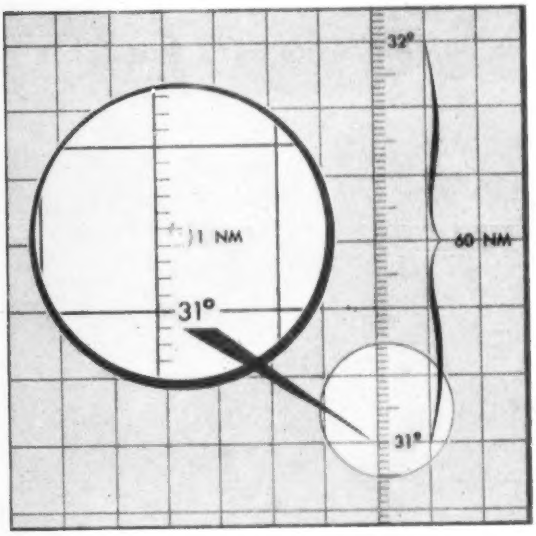


Figure 3-26. Latitude Provides a Convenient Graphic Scale

DOD CATALOG OF AERONAUTICAL CHARTS AND FLIGHT INFORMATION PUBLICATIONS. This catalog provides information on the latest aeronautical cartographic products produced and/or distributed by the Defense Mapping Agency Aerospace Center (DMAAC) and the Defense Mapping Agency Hydrographic Center (DMAHC). A brief description of each series or type of chart listed in this catalog is presented with the appropriate index or listing. Chart samples are given for each series indexed in Sections IV, V, and VI. The DOD Catalog is divided into the following sections:

Section I. General Information—The overall purpose of this section is to acquaint users with information within the catalog. It also provides basic information on projections and a variety of other basic cartographic data.

Section II. Requisitioning and Distribution Procedures.

- General Procedures—A detailed description of procedures to follow in normal requisitioning of charts and publications by USAF activities and other authorized agencies. This section contains samples of requisitioning forms and charts depicting areas of distribution and defines responsibilities for issuance and procurement of charts and publications.
- Uniform Material Movement and Issue Priority System (UMMIPS)—A detailed description of the priority system to follow when requisitioning charts and publications.

Section III. Flight Information Publications (FLIPS)—These publications consist of that textual and graphic information required to plan and conduct an IFR flight. FLIPS are separated into three basic categories corresponding to phases of flight as follows:

- Planning—Complete description of (1) Flight Information Publication Planning Document which includes Planning Data and Procedures; Military Training Routes, United States; International Rules and Procedures and Regulations, (2) FLIP Planning Charts, and (3) Foreign Clearance Guide.
- Enroute—A complete listing of DOD Enroute Charts and Supplements covering United States, Alaska, Canada and North Atlantic, Caribbean and South America, Europe and North Africa, Africa and Southwest Asia, Australia, New Zealand, Antarctica, the Pacific and Southeast Asia; TACAN Facility Chart coverage of Alaska also included.
- Terminal—Describes the DOD publications which contain approved Low and High Altitude Instrument Approach Procedures and Aerodrome Sketches.

Section IV. Navigational Charts—This section contains a general description of the scale, code, projection, size, purpose, cartographic style, and information shown on navigational charts. They are grouped in three categories: general purpose, special purpose, and plotting charts.

Section V. General Planning—This section contains a general description of the scale, code, projection, size, purpose, style, and information shown on all charts used for planning references and/or wall displays.

Section VI. Special Purpose—This section outlines all requisitioning procedures for the special purpose charts along with a brief description of their purpose.

AERONAUTICAL CHART CURRENCY AND UPDATING INFORMATION.

DOD Bulletin Digest. This document is published semi-annually in both classified and unclassified versions. It provides a complete cumulative listing of current chart editions available for distribution to users. Information available in these documents (within each chart series) is the chart number, current edition, and date of edition.

DOD Bulletin. This document is published monthly in both classified and unclassified versions. It provides a listing of the availability of new aeronautical charts, new editions of previously published charts, discontinued charts, miscellaneous ICAO and FAA publications and amendments, requisitioning information, and charts scheduled for completion. This document supplements the Bulletin Digest.

DOD Chart Updating Manual (CHUM). This document is published monthly in both classified and unclassified versions. It lists, for each current chart edition, corrections and additions which could affect flying safety. The CHUM should be found in all flight planning rooms. The additions and corrections listed for the appropriate charts should be checked and the applicable ones annotated on the charts.

TYPES OF CHARTS. Aeronautical charts are differentiated on a functional basis by the type of information they contain. Navigation charts are grouped into three major types: general purpose, special purpose, and plotting. The name of the chart is a reasonable indication of its intended use. Thus, a Consol Chart has information needed by the navigator to use Consol as a navigation aid; a Minimal Flight Planning Chart is primarily used in minimal flight planning techniques; and a Jet Navigation Chart has properties that make it adaptable to the speed, altitude, and instrumentation of jet aircraft. In addition to the specific type of information contained, charts vary according to the amount of information displayed. Charts designed to facilitate the planning of long distance flights carry less detail than those required for navigation en route. Local charts present great detail. Figure 3-27 shows a comparison of various charts at different scales.

Chart Symbols

Standard symbols (atch 1) are used for easy identification of information portrayed on aeronautical charts. While these symbols may vary slightly between various projections, the amount of variance is slight and once the basic symbol is understood, variations of it are easy to identify. A chart legend is the key which explains the meaning of the relief, culture, hydrography, vegetation, and aeronautical symbols, as shown in figure 3-28.

RELIEF (Hypsography). Chart relief shows the physical features related to the differences in eleva-

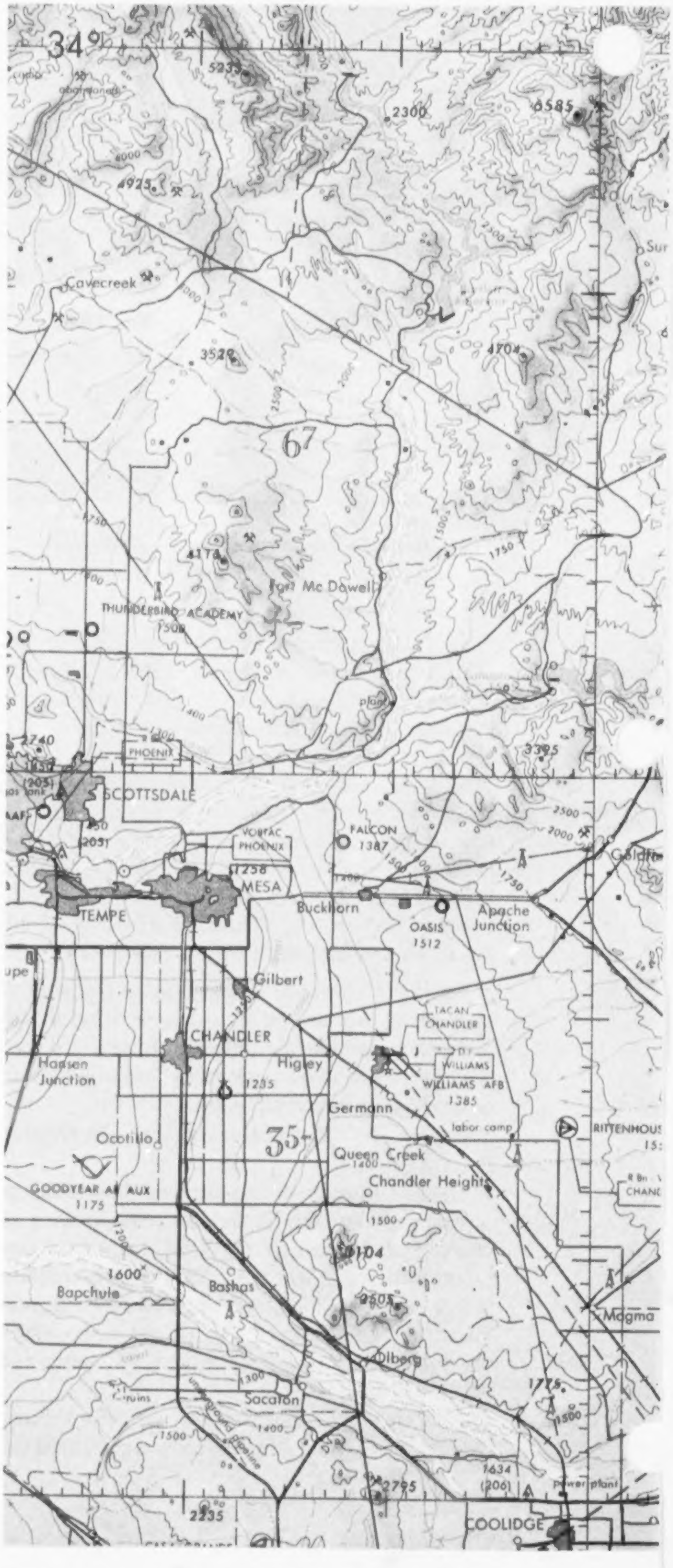
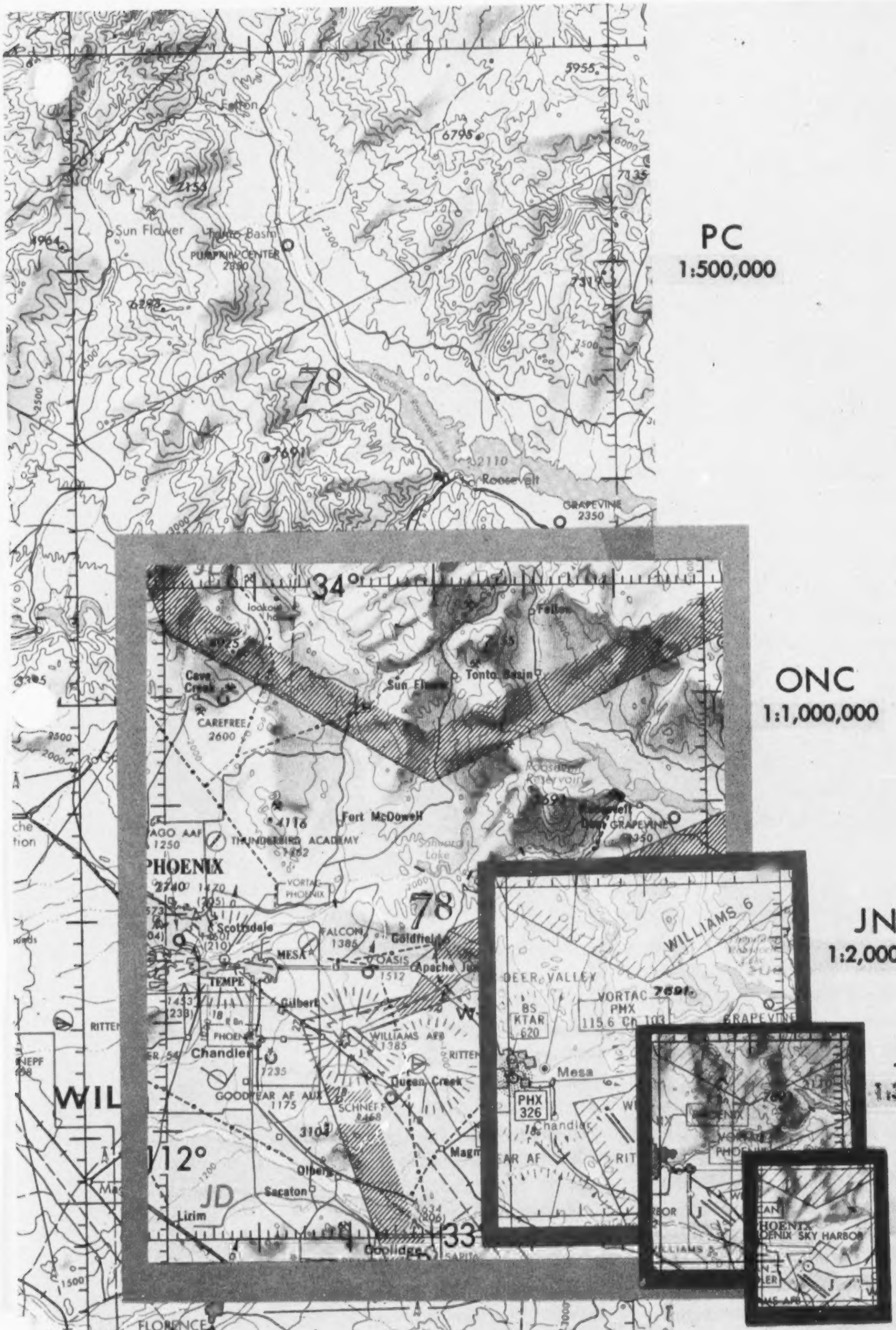

34°
67
35
Cavecreek
Fort Mc Dowell
THUNDERBIRD ACADEMY
SCOTTSDALE
PHOENIX
FALCON
MESA
TEMPE
Buckhorn
OASIS
Apache Junction
Gilbert
CHANDLER
Higley
Hansen Junction
WILLIAMS AFB
Germann
Ocotillo
Queen Creek
Chandler Heights
GOODYEAR AF AUX
Bapchule
Bashas
Olberg
Sacaton
Magma
RITTENHOUSE
COOLIDGE
labor camp
Power plant

Figure 3-27. Scale Comparison of Aeronautical Charts


PC
1:500,000
ONC
1:1,000,000
JN
1:2,000,000
JNC
1:3,000,000
GNC
1:5,000,000
Sun Flower
Tonto Basin
PUMPKIN CENTER
Roosevelt
GRAPEVINE
78
34°
Cave Creek
CAREFREE
Fort McDowell
THUNDERBIRD ACADEMY
PHOENIX
Scottsdale
FALCON
MESA
TEMPE
Gilbert
Chandler
WILLIAMS AFB
Queen Creek
Olberg
Sacaton
Coolidge
112°
JD
33°
FLORENCE
VALLEY FARMS
DEER VALLEY
VORTAC PHX
Mesa
PHX 326
WILLIAMS
PHOENIX SKY HARBOR

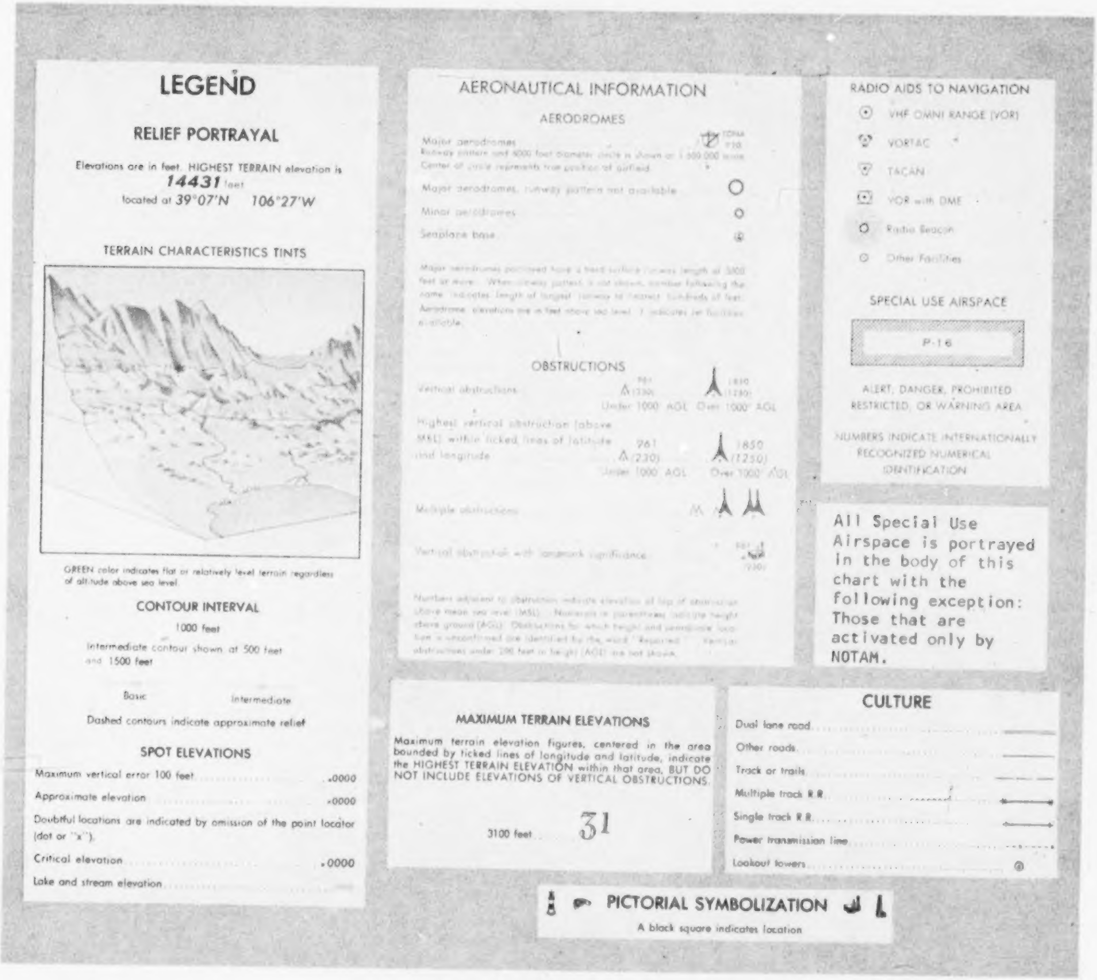

LEGEND
RELIEF PORTRAYAL
Elevations are in feet. HIGHEST TERRAIN elevation is 14431 feet located at 39°07'N 106°27'W
TERRAIN CHARACTERISTICS TINTS
GREEN color indicates flat or relatively level terrain regardless of altitude above sea level
CONTOUR INTERVAL
1000 feet
Intermediate contour shown at 500 feet and 1500 feet
Basic
Intermediate
Dashed contours indicate approximate relief
SPOT ELEVATIONS
Maximum vertical error 100 feet
Approximate elevation
Doubtful locations are indicated by omission of the point locator (dot or "x").
Critical elevation
Lake and stream elevation
AERONAUTICAL INFORMATION
AERODROMES
Major aerodromes
Minor aerodromes
Seaplane base
OBSTRUCTIONS
Vertical obstructions
Under 1000' AGL
Over 1000' AGL
Multiple obstructions
RADIO AIDS TO NAVIGATION
VHF OMNI RANGE (VOR)
VORTAC
TACAN
VOR with DME
Radio Beacon
Other Facilities
SPECIAL USE AIRSPACE
P-16
ALERT, DANGER, PROHIBITED RESTRICTED, OR WARNING AREA
NUMBERS INDICATE INTERNATIONALLY RECOGNIZED NUMERICAL IDENTIFICATION
All Special Use Airspace is portrayed in the body of this chart with the following exception: Those that are activated only by NOTAM.
MAXIMUM TERRAIN ELEVATIONS
Maximum terrain elevation figures, centered in the area bounded by ticked lines of longitude and latitude, indicate the HIGHEST TERRAIN ELEVATION within that area, BUT DO NOT INCLUDE ELEVATIONS OF VERTICAL OBSTRUCTIONS.
3100 feet
31
CULTURE
Dual lane road
Other roads
Track or trails
Multiple track R.R.
Single track R.R.
Power transmission line
Lookout towers
PICTORIAL SYMBOLIZATION
A black square indicates location

Figure 3-28. Sample Chart Legend

tion of the land surface. These include features such as mountains, hills, plateaus, plains, depressions, etc. Standard symbols and shading techniques are used in relief portrayal on charts; these include contours, spot elevations, variations in tint, and shading to represent shadows.

Contour Lines. A contour is a line connecting points of equal elevation. Figure 3-29 shows the relationship between contour lines and terrain. Notice that on steep slopes the contours are close together and on gentle slopes they are farther apart. The interval of the contour lines usually depends upon the scale of the chart and the terrain depicted. In the illustration, the contour interval is 1,000 feet. Depression contours are regular contour lines with spurs or ticks added on the downslope side.

Spot Elevations. Spot elevations are the height of a particular point of terrain above an established datum, usually sea level.

Gradient Tints. The relief indicated by contours is further emphasized on charts by a system of gradient tints. They are used to designate areas within certain elevation ranges by different color tints.

Shading. Perhaps the most obvious portrayal of relief is supplied by graduated shading applied to the "southeastern" side of elevated terrain and the "northwestern" side of depressions. This shading simulates the shadows cast by elevated features,

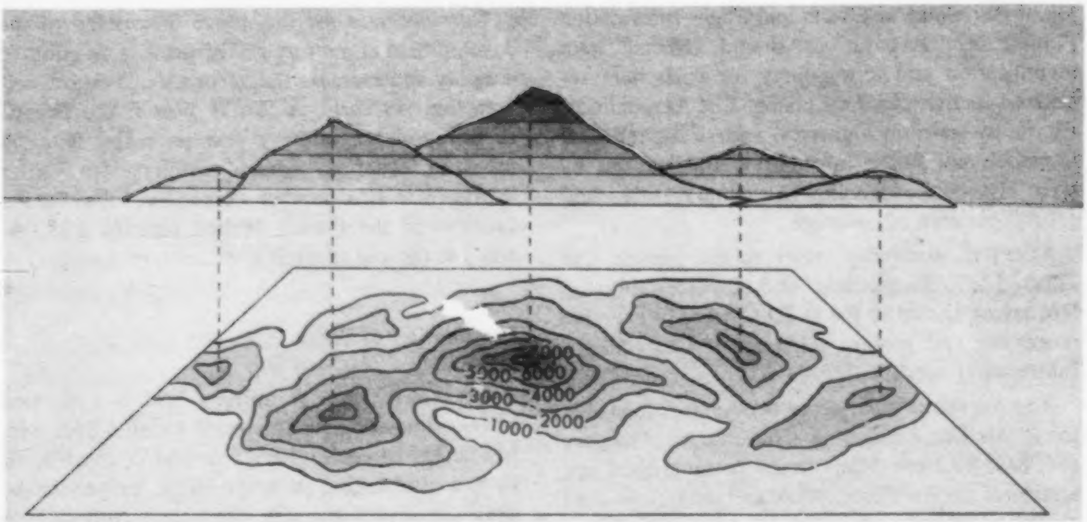


Figure 3-29. Contour Lines

lending a sharply defined, three-dimensional effect.

Cultural Features. All man-made structures appearing on the terrain are known as cultural features. Three main factors govern the amount of detail given to cultural features: (1) the scale of the chart, (2) the use of the chart, and (3) the geographical area covered. Populated places, roads, railroads, installations, dams, bridges, and mines are some of the many kinds of cultural features portrayed on aeronautical charts. The true representative size and shape of larger cities and towns are shown. Standardized coded symbols and type sizes are used to represent the smaller population centers. Some symbols denoting cultural features are usually keyed in a chart legend. However, some charts use pictorial symbols which are self-explanatory. These require no explanations in the legend.

HYDROGRAPHY. In this category, aeronautical charts portray oceans, coast lines, lakes, rivers, streams, swamps, reefs, and numerous other hydrographic features. Open water may be portrayed by tinting, by vignetting, or may be left blank.

VEGETATION. Vegetation is not shown on most small scale charts. Forests and wooded areas in certain parts of the world are portrayed on some medium scale charts. On some large scale charts, park areas, orchards, hedgerows, and vineyards are shown. Portrayal may be by solid tint, vignette, or supplemented vignette.

AERONAUTICAL INFORMATION. In the aeronautical category, coded chart symbols denote airfields, radio aids to navigation, commercial broadcasting stations, Air Defense Identification Zones (ADIZ), compulsory corridors, restricted airspace, warning notes, lines of magnetic variation, and special navigation grids. Some aeronautical information is subject to frequent change. For economy of production, charts are retained in stock for various periods of time. So as not to provide the chart user with aeronautical information that is rapidly out of date, only the more "stable" type information is printed on navigation charts. Aeronautical type data subject to frequent change is provided the user by the DOD Flight Information Publications (FLIP) documents. Consult the DOD Flight Information Publications (FLIP), Chart Updating Manual (CHUM), and Notices to Airmen (NOTAMS) for the most current air information and/or chart information.

Procurement/Requisitioning of Charts/Flight Information Publications

All aeronautical charts and flight information publications produced and/or distributed by the Defense Mapping Agency Aerospace Center (DMAAC) or any of its overseas flight information offices are requisitioned in accordance with procedure outlined in Section II of the DOD Catalog of Aeronautical Charts and Flight Information Publications. Requisitions should indicate item identification and terminology for each item requested, as listed in the Catalog. List Aeronautical Charts by series in numerical and/or alphabetical sequence and Flight Information Publications by type (Enroute, Planning, Terminal), title, and geographic area of coverage.

When requisitioning, refer to the sample DD Form 1149, Requisition and Invoice Shipping Document, shown in the DOD Catalog to expedite processing and prompt shipment of Chart/Flight Information needs.

The Air Force Intelligence Service is responsible for all Air Force Mapping, Charting, and Geodesy (MC&G) matters. Many times in the tactical operation of the Air Force, pilots and navigators need new or additional cartographic support in performing their navigational duties. The following information tells them how to submit requirements for developing or modifying MC&G products.

- Air Force organizations, except those designated as specified commands or components of unified commands, submit their MC&G product requirements through command channels to Air Force Intelligence Service (AFIS/INTB), Washington D.C. 20330, in accordance with AFR 96-9.
- Air Force Commands designated as specified commands or components of unified commands submit MC&G Product Requirements according to DMA directives and unified or specified command instructions. Forward an information copy of the requirements to Air Force Intelligence Service (AFIS/INTB), Washington, D.C. 20330.
- All Air Force organizations may contact the Defense Mapping Agency Aerospace Center (DMAAC) or its squadrons and detachments for technical assistance in preparing statements of requirements. Addressees are listed in the DOD Catalog of Aeronautical Charts and Flight Information Publications.

POSITION REFERENCING SYSTEMS

The spherical coordinate system of latitude and longitude sometimes proves difficult to use because its units of degrees, minutes, and seconds are not comparable to the normal units of surface measurement. Further, the geographic graticule is not printed in its entirety on most topographic maps.

Consideration for the above factors led to the development of military grid systems in an effort to simplify and increase the accuracy of position referencing. As early as World War I, the French superimposed a military grid on maps of small areas in order to control artillery fire. After World War I, a number of nations followed the example of the French-devised military grid system for the use of their own military forces.

Explanation of Terms

Military Grid. A military grid is composed of two series of equally spaced parallel lines perpendicular to each other. The grid is constructed by first establishing an origin. Next, perpendicular axes are drawn through the origin with one of them pointing true north. North-south grid lines (eastings) and east-west grid lines (northings) are then drawn parallel and perpendicular, respectively, to the north-south axis. On military maps of scale 1:75,000 and larger, the distance between successive grid lines (grid interval) represents 1,000 meters (or yards) at the scale of the map. The military grid is superimposed on charts and maps to permit accurate identification of ground positions and to allow the computing or measuring of correct distances and directions from one point to another. The origin is assigned false values to avoid coordinates of negative value. Grid lines are identified by grid line values printed in two sizes of type in the margin at each end of the grid line. For referencing purposes, only the grid line values printed in the larger type size (principal digits), increased by any digits needed to express the reference to the desired degree of accuracy, are used. Grid line values increase from west to east and from south to north.

Position Referencing System. A position referencing system is any system which permits the designation of a point or an area on the earth's surface, usually in terms of numbers or letters, or a combination thereof.

World Position Referencing System. References for points taken from charts or maps not gridded with a military grid are expressed as geographic coordinates in terms of latitude and longitude.

Military Grid Reference System (MGRS). This is a position referencing system developed for use with the Universal Transverse Mercator

(UTM) and Universal Polar Stereographic (UPS) grids.

WORLD GEOGRAPHIC REFERENCE SYSTEM (GEOREF). This is a referencing system sometimes employed by the Air Force in the control and direction of air forces engaged in operations not involving other military forces.

General Information

DOD POLICY FOR POSITION REFERENCING. It is possible for the practicing navigator to encounter any or all of the basic reference systems discussed in this manual. The Department of Defense policy for position referencing procedures for joint use by all the U.S. military services establishes two position referencing systems for all joint operations as follows:

1. The system of geographic coordinates expressed in latitude and longitude.
2. The Military Grid Reference System (MGRS) as developed for use with the UTM and UPS grids.

RELATIONSHIP OF MILITARY GRIDS TO MAP PROJECTIONS. Because military grids are designed to permit accurate identification of ground locations and the computation of distance and direction from one point to another, and because all map projections have inherent distortion of scale and angles, it is essential that military grids be superimposed upon projections having the least distortion. Conformal projections selected by the Department of Defense as having the least distortion of scale and angles for large and medium scale mapping are the transverse Mercator and the polar stereographic. The military grid systems are applied to aeronautical charts primarily for use in Air Force support of ground operations. The Air Force uses the Universal Transverse Mercator (UTM) from latitude 80°S to 84°N and the Universal Polar Stereographic (UPS) from latitudes 84°N and 80°S to the respective poles. The standard unit of measure used with UTM and UPS grids is the meter.

Military Grid Reference System

GENERAL DESCRIPTION. The Military Grid Reference System is designed for use with the UTM and UPS Grids.

The world is divided into large, regularly shaped geographic areas, each of which is given a unique identification, called the Grid Zone Designation. These areas are subdivided into 100,000-meter squares, based on the grid covering the area. Each square is identified by two letters called the 100,000-meter square identification. This identification is unique within the area covered by the Grid Zone Designation. Numerical references within the 100,000-meter square are given to the desired accuracy in terms of the easting (E) and northing (N) grid coordinates for the point.

Ordinarily, a reference keyed to a large scale map is expressed only in numerical terms. However, if reporting is beyond 100,000 meters, and in certain other cases, the reference is prefixed with the 100,000-meter square identification. Further, if reporting is beyond 18° in any direction (limited to 9° north or south in certain cases), the reference is prefixed with the Grid Zone Designation.

Ordinarily, a reference keyed to a medium scale map is made by giving the 100,000-meter square identification together with the numerical term. The Grid designation is usually prefixed only if reporting is beyond 18° in any direction (limited to 9° north or south in certain cases).

GRID ZONE DESIGNATION FOR UTM GRIDS. Between 84° north and 80° south, the globe is divided into areas 6° east-west by 8° north-south. Between 72° north and 84°N, the bands are not always 6° wide. The columns (6° wide) are identified by the Universal Transverse Mercator (UTM) Zone numbers; i.e., starting at the 180° meridian and proceeding easterly, the columns are numbered 1 through 60, consecutively (figure 3-30). The rows (8° high, except for the last which is 12° high) are identified by letters; starting at 80° south and proceeding northerly to 84° north, the rows are lettered alphabetically C through X with the letters I and O omitted. The grid zone designation of any 6° east-west by 8° or 12° north-south area is determined by reading to the right, first the column designation (as, 32), and second up, the row designation (as T), as 32T (see figure 3-30).

100,000-METER SQUARE IDENTIFICATION FOR UTM GRIDS. Between 84° north and 80° south, each 6° by 8° or 12° area is divided into 100,000-meter squares based on the UTM Grid for the zone. Each column of squares is identified by a letter; likewise, each row of squares is identified by a letter. Starting at the 180° meridian and proceeding easterly along the equator for 18°,

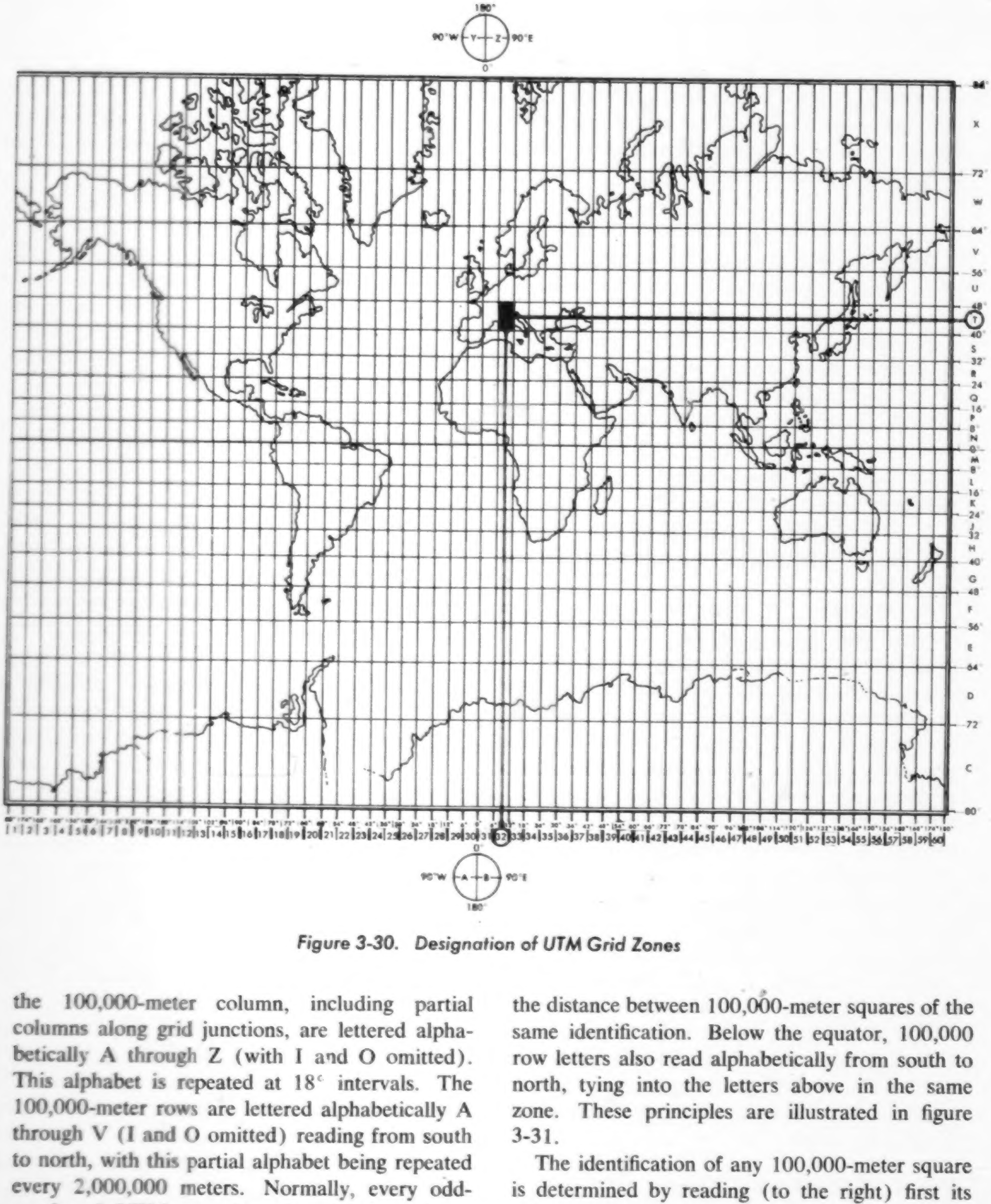

180°
90°W
Y
Z
90°E
0°
84°
X
72°
W
64°
V
56°
U
48°
T
40°
S
32°
R
24°
Q
16°
P
8°
N
0°
M
8°
L
16°
K
24°
J
32°
H
40°
G
48°
F
56°
E
64°
D
72°
C
80°
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
0°
90°W
A
B
90°E
180°

Figure 3-30. Designation of UTM Grid Zones

the 100,000-meter column, including partial columns along grid junctions, are lettered alphabetically A through Z (with I and O omitted). This alphabet is repeated at 18° intervals. The 100,000-meter rows are lettered alphabetically A through V (I and O omitted) reading from south to north, with this partial alphabet being repeated every 2,000,000 meters. Normally, every odd-numbered UTM zone has the alphabet of the 100,000-meter row letters beginning at the Equator; the even-numbered UTM zones normally have the alphabet of the 100,000-meter row letters beginning at the northing grid line 500,000 meters south of the equator. This staggering lengthens the distance between 100,000-meter squares of the same identification. Below the equator, 100,000 row letters also read alphabetically from south to north, tying into the letters above in the same zone. These principles are illustrated in figure 3-31.

The identification of any 100,000-meter square is determined by reading (to the right) first its column letter (as N) and (then up) second its row letter (as L) giving NL in figure 3-32.

Under this system, a 100,000-meter square identification usually is not repeated within 18° in any direction. This normally eliminates the necessity within such distances for preceding grid

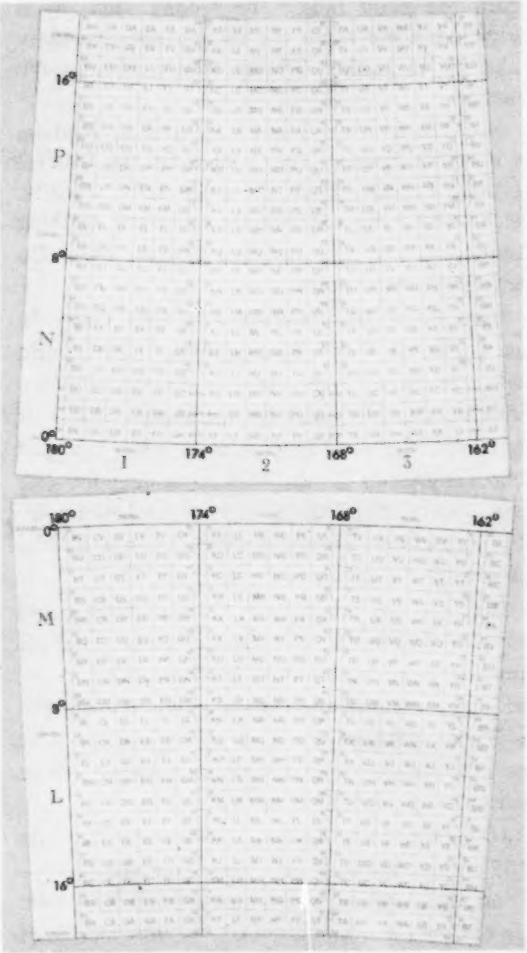


Figure 3-31. Designation of 100,000-Meter Squares, UTM Grid

Locating a Military Grid Reference

A Military Grid reference consists of a group of letters and numbers which indicate (1) the Grid Zone Designation, (2) the 100,000-meter square identification, and (3) the grid coordinates—the numerical reference—of the point expressed to the desired accuracy. A reference is written as a continuous number without spaces, parentheses, dashes, or decimal points.

Examples:

- 32TNL—Locating a point within a 100,000-meter square
- 32TNL73—Locating a point within a 10,000-meter square
- 32TNL7438—Locating a point within 1,000 meters
- 32TNL743385—Locating a point within 100 meters

To satisfy special needs, a reference can be given to the nearest 10 meters and the nearest 1 meter.

Examples:

- 32TNL74343856—Locating a point within 10 meters
- 32TNL7434238565—Locating a point within 1 meter

Normally, all elements of a grid reference are not used. Those to be omitted depend upon the size of the area of activities, the proximity of a spheroid junction and the scale of the map to which the reference is keyed (interval of grid lines). To give the position of a point, first give the grid zone designation, then the 100,000-meter square, such as 32TNL. Notice that the reference is written in a continuous group—no spaces,

references with the Grid Zone Designation even though the report is being made from as many as two grid zones away.

To prevent ambiguity of identifications along spheroid junctions, changes in the order of the row letters are necessary. The row alphabet is shifted ten letters. In such cases, a decrease results in the maximum distance by which 100,00-meter square identifications are not repeated. Thus when reporting a point from a sheet which falls within 9° north or south of a spheroid junction, the Grid Zone Designation can be omitted only if reporting is not beyond 9° north or south or beyond 18° east or west.

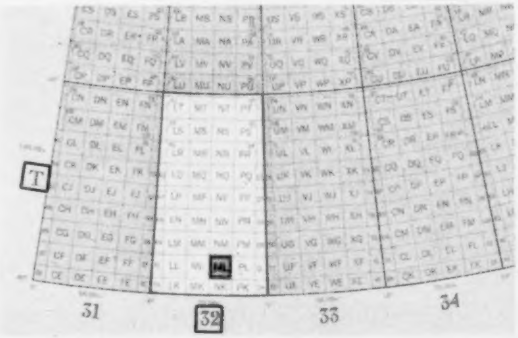


Figure 3-32. Identification of 100,000-Meter Square (NL) Within UTM Zone 32T

parentheses, dashes, or decimal points. The designation 32TNL describes the 100,000-meter square (NL) that is located in the 6° by 8° grid zone, 32T. The origin of every 100,000-meter square is 0,0. To reference a point within a 100,000-meter square, give the grid coordinates of the point. The grid coordinates are designated by an even number of digits. The first half of this number, no matter how small or large, is the easting; the second half, the northing. The reference 32TNL7434238565 locates an object within a 1-meter square. The number 74342 is the easting (read to the right) coordinate, while 38565 is the northing (read up) coordinate which locates a point within a one-meter square of the 100,000-meter square designated as NL and in grid zone 32T (figure 3-33).

Sample Reference, UTM Grid. To illustrate the procedure for locating a point by the UTM Grid system, a fictitious example point identified within a reference box accompanies each grid overprint as shown in figure 3-34. Using the sample reference, the following procedure illustrates how to locate the point whose standard reference is: 32TNL7438.

- 32T—identifies the 6° by 8° grid zone in which the point is located.
- NL—identifies the 100,000-meter square in which the point is located.
- 74—The numbers 7 and 4 are both right reading, or easting figures. The first of these two digits, 7, identifies the interval easting beyond which the point falls. The second digit, 4, is estimated; it represents the value of the imaginary 1,000-meter easting column which includes the point.
- 38—The numbers 3 and 8 are both up reading, or northing figures. The 3 identifies the interval northing beyond which the point falls. Finally, the 8 defines the 1,000-meter estimated northing required to complete the area dimensions of the sample reference point.

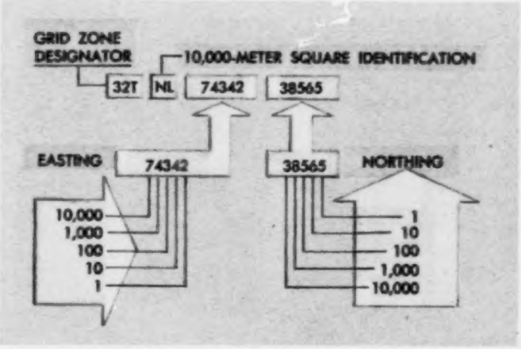


Figure 3-33. Grid Coordinates 32TNL7434238565 Identify a 1-Meter Square

Grid Zone Designation for UPS Grid. In the Universal Polar Stereographic (UPS) grid zone, the North Polar Area is divided into two parts by the 180° and 0° meridians. The half containing the west longitudes is given the grid zone designation Y; the half containing the east longitudes is given the grid zone designation Z. No numbers are used in conjunction with the letter to give a grid zone designation.

Similarly, the South Polar Area is divided into two parts by the 0° and 180° meridians. The half containing the west longitude is identified as A; the half containing the east longitude is identified as B. No numbers are used in conjunction with the letter to give a grid zone designation. These divisions are illustrated in figure 3-35.

100,000-Meter Square Identification for UPS Grids. In the North Polar Area, the 180°—0° meridians coincide with an even 100,000-meter vertical grid line and the 90° — 90° meridians coincide with an even 100,000-meter horizontal grid line. Grid north is coincident with the 180° meridian from the Pole. In the half of the area identified by the Grid Zone Designation Y, the 100,000-meter columns (these are at right angles to the 90° — 90° meridians) are labeled R through Z alphabetically from left to right. In the half identified by the Grid Zone Designation Z, the 100,000-meter columns are labeled A through J alphabetically from left to right; in this case the letter I is omitted, and to avoid confusion with 100,000-meter squares in adjoining UTM zones, the letters D, E, V, and W are omitted. Starting at the 84° parallel and reading toward grid north, the 100,000-meter rows at right angles to the 180° — 0° meridians are alphabetically labeled A through P (I and 0 omitted). The identification of a 100,000-meter square consists of two letters

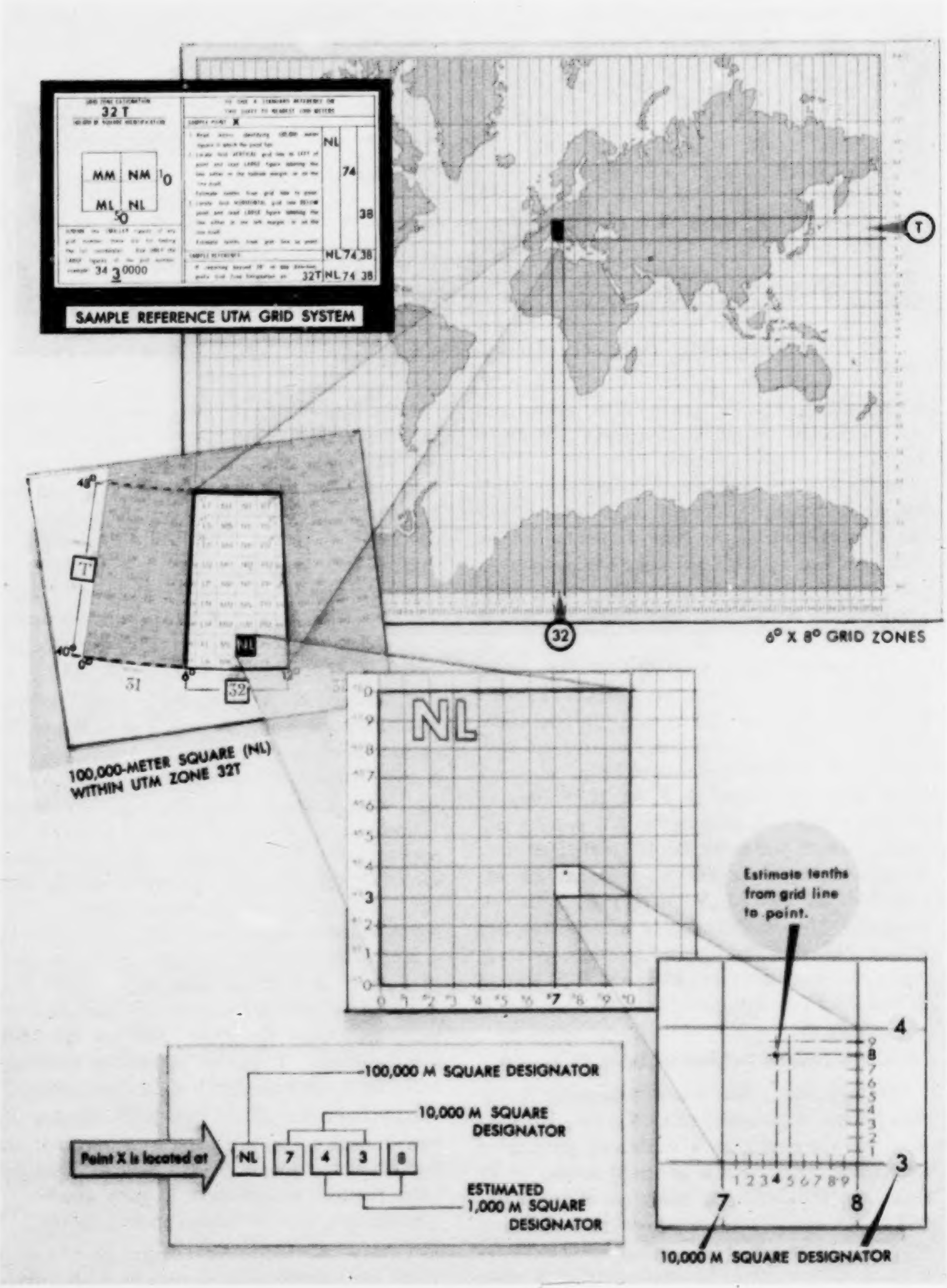

32 T
MM
NM
ML
NL
34 3 0000
NL
74
38
NL 74 38
32T NL 74 38
SAMPLE REFERENCE UTM GRID SYSTEM
T
32
6° X 8° GRID ZONES
48°
40°
0°
6°
12°
31
32
100,000-METER SQUARE (NL) WITHIN UTM ZONE 32T
NL
Estimate tenths from grid line to point.
100,000 M SQUARE DESIGNATOR
10,000 M SQUARE DESIGNATOR
Point X is located at
NL
7
4
3
8
ESTIMATED 1,000 M SQUARE DESIGNATOR
4
3
7
8
10,000 M SQUARE DESIGNATOR

Figure 3-34. Using UTM Grid System to Locate a Point

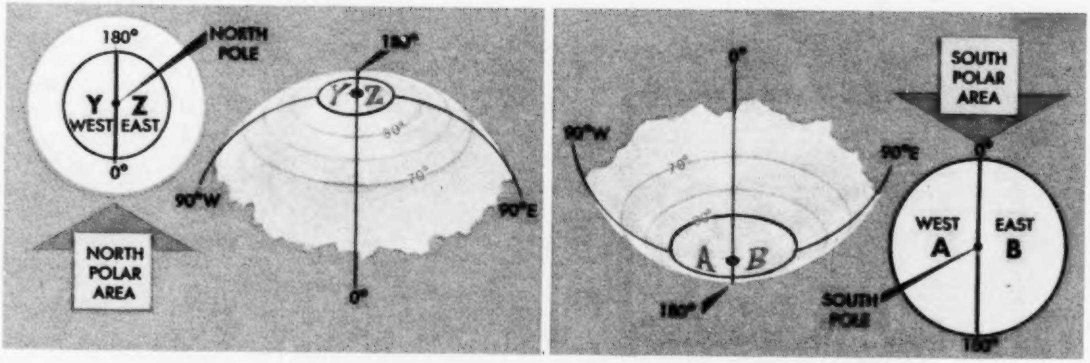


Figure 3-35. Designation of Universal Polar Stereographic (UPS) Grid Zone

determined by reading (right) first its column letter and (up) second its row letter (see figure 3-36).

In the South Polar Area, a similar plan is followed, except that grid north is coincident with the 0° meridian from the Pole. In the half of the area identified by the Grid Zone Designation A, the 100,000-meter columns (these are at right angles to the 90° — 90° meridians) are labeled J through Z alphabetically from left to right. In the half identified by the Grid Zone Designation B, the 100,000-meter columns are labeled A through R alphabetically from left to right. In both cases the letters I and O are omitted, and, to avoid confusion with 100,000-meter squares in adjoining UTM zones, the letters D, E, M, N, V, and W are also omitted. Starting at the 80° parallel and reading toward grid north, the 100,000-meter rows at right angles to the 180°— 0° meridians are alphabetically labeled A through Z (I and 0 omitted). The identification of a 100,000-meter square consists of two letters determined by reading (right) first its column letter and (up) second its row letter (see figure 3-37).

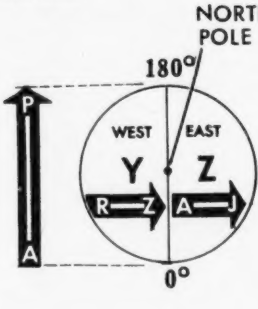
World Geographic Reference (GEOREF) System

DEVELOPMENT. The World Geographic Reference System was developed by the Air War College, Air University, as a worldwide geographic referencing system and is generally known by its short title "GEOREF." It makes use of the simplified system of always reading from left to right and up, using a group of letters and numbers to locate a point, thus making the referencing of a point much easier than using the geographic coordinates of latitude and longitude which require the giving of latitude in degrees, minutes, and seconds (north or south) and the longitude in degrees, minutes, and seconds (east or west). For example, to call in a reference to the nearest minute using geocoordinates it would be necessary to say, "60 degrees, 12 minutes north, by 119 degrees 57 minutes east" as compared to a reference to the same point using the GEOREF system "VLQA-5712." The possibility of error in communicating a reference is greatly reduced by the relatively simple GEOREF system.

COMPOSITION. The GEOREF system is based on the normal longitude and latitude values that appear on all maps and charts. Instead of using a grid system of its own, as does the UTM grid and other military grids, the GEOREF system makes use of the meridians and parallels that appear on the chart. Basically, this system defines the unit geographic area in which a specific point lies. It may be applied to any map or chart regardless of the type of projection. The GEOREF is read to the right and up in all cases. The point of origin is the 180th meridian and the South Pole. It extends to the right or eastward from the 180th meridian around the globe, 360° to the 180th meridian again. It extends upward or northward from the South Pole, 180° to the North Pole.

REFERENCING. The GEOREF divides the earth's surface into quadrangles of longitude and latitude with a simple, brief, systematic code that gives positive identification to each quadrangle. The system and identification codes include:

- Twenty-four longitudinal zones of 15° each, which are lettered from A through Z (omitting I and O) eastward from the 180th meridian. Twelve bands of latitude, each 15° wide, lettered from A


NORTH POLE
180°
WEST
EAST
Y
Z
P
A
R—Z
A—J
0°

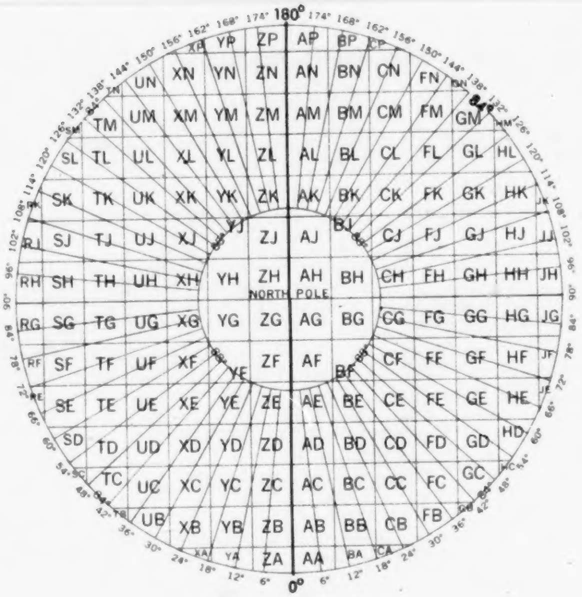
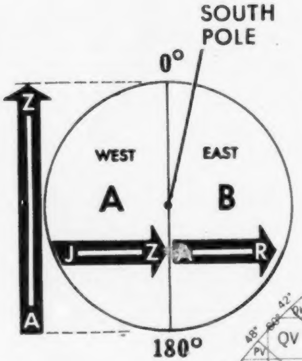

180°
NORTH POLE
84°
0°

Figure 3-36.
North Polar Area
UPS Grid

WEST EAST


SOUTH POLE
0°
WEST
EAST
A
B
Z
A
J—Z
A—R
180°

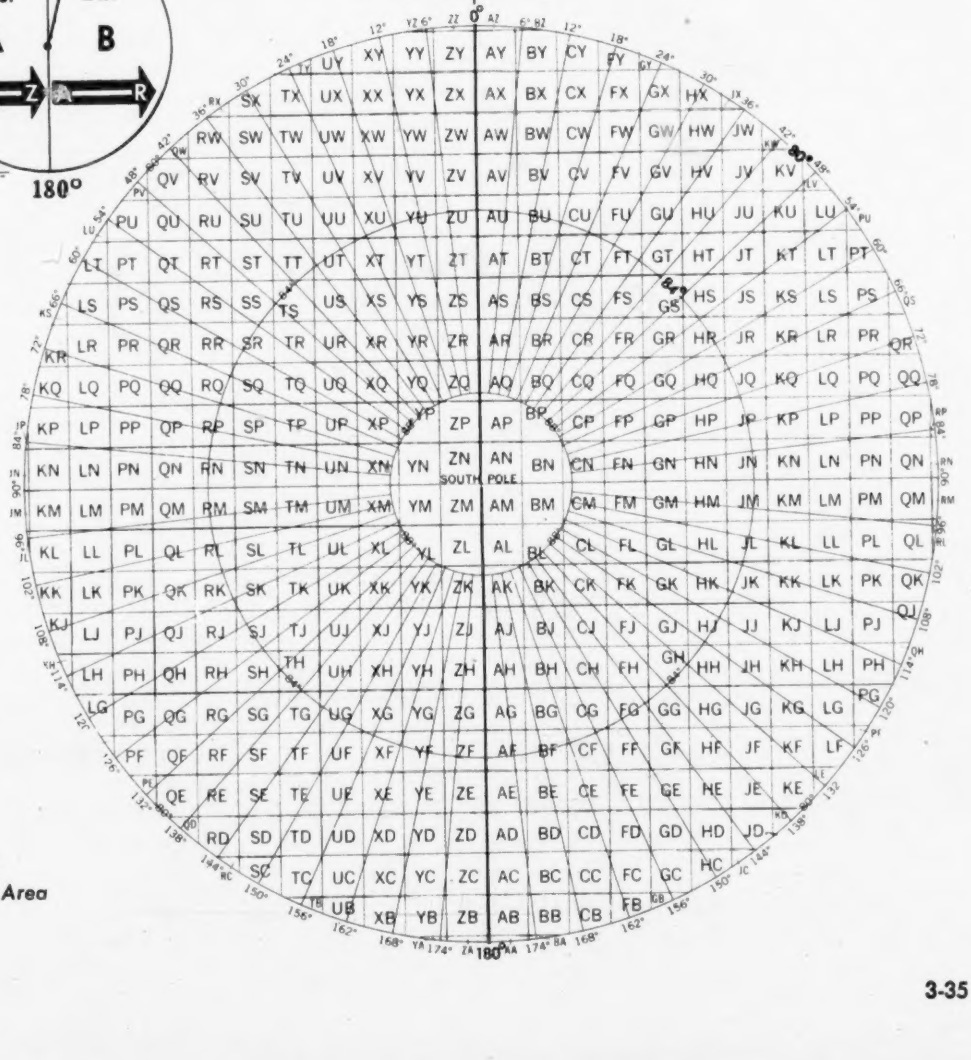

0°
SOUTH POLE
80°
84°
180°

Figure 3-37.
South Polar Area
UPS Grid

WORLD GEOGRAPHIC REFERENCE SYSTEM (GEOREF) INDEX

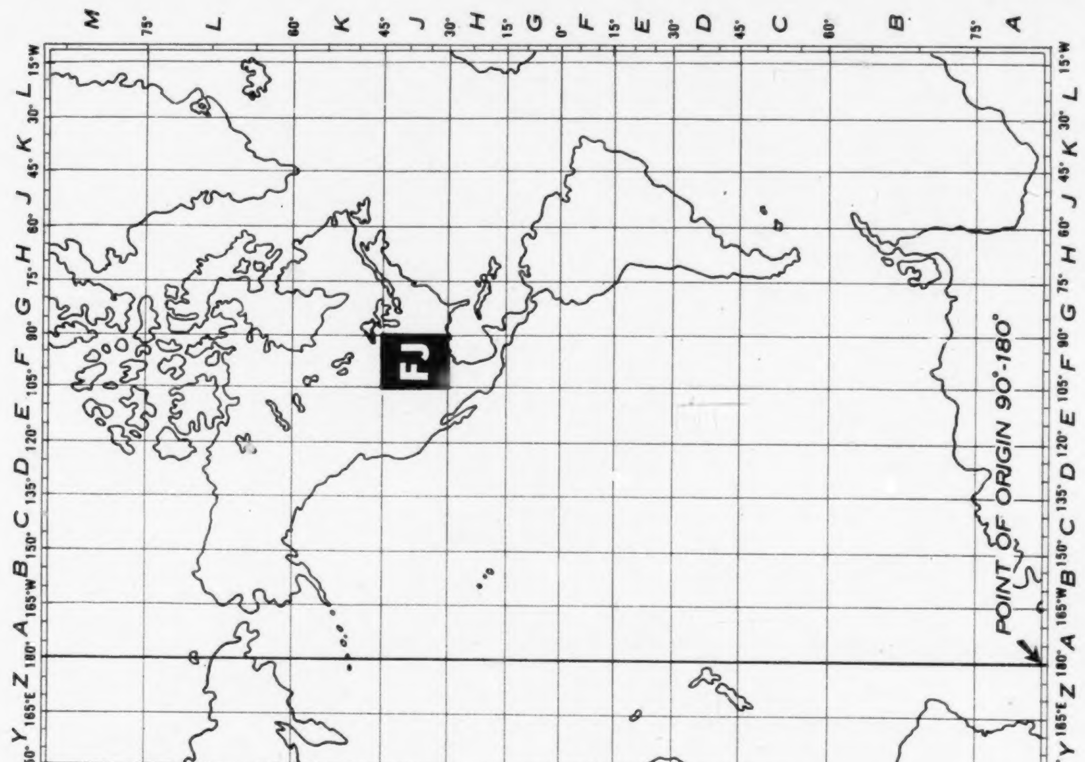

FJ
POINT OF ORIGIN 90°-180°
M N P Q R S T U V W X Y Z A B C D E F G H J K L
15°W 0° 15°E 30° 45° 60° 75° 90° 105° 120° 135° 150° 165°E 180° 165°W 150° 135° 120° 105° 90° 75° 60° 45° 30° 15°W
A B C D E F G H J K L M
75° 60° 45° 30° 15° 0° 15° 30° 45° 60° 75°

Figure 3-38. Location of 15° Quadrangle FJ, GEOREF Index

through M (omitting I) northward from the South Pole. This combination divides the earth's surface into 288 basic 15° quadrangles, each identified by two letters. In local operations confined to a single chart or to a single 15° quadrangle, these letters may be dropped. On small scale charts, the letter designators are shown in large letters in the southwest corner of each 15° quadrangle. On larger scale charts, the 15° quadrangle designators are shown in the area between the neat line and border. When the southwest corner of a 15° quadrangle falls in the chart area, the designators also are shown in the southwest corner of the quadrangle. The world-wide breakdown is illustrated by figure 3-38.

- Each basic 15° quadrangle is divided into 15 lettered one-degree units eastward and 15 lettered one-degree units northward from A through Q (omitting I and O). Thus, two additional letters (four in all) identify any one-degree quadrangle in the world. Figure 3-39 illustrates the alphabetical breakdown of a 15° quadrangle.
- Each one-degree quadrangle is divided into 60 numbered "minute" units eastward and northward. Thus four letters and four figures identify a one-minute quadrangle anywhere in the world. This breakdown permits location of a point within approximately one nautical mile. This manner of numbering is used wherever the one-degree quadrangle is located; it does not vary even though the location may be west of the Greenwich meridian or south of the equator. The GEOREF minutes of longitude always increase from West to East, and the GEOREF minutes of latitude always increase from South to North. This is contrary to the geographic minutes of latitude in the Southern hemisphere and the geographic minutes of longitude in the Western hemisphere.

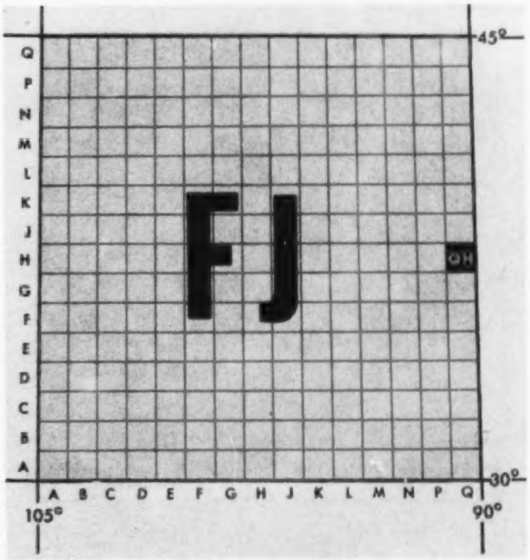
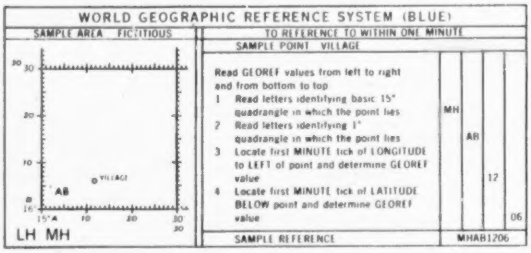


Figure 3-39. GEOREF 15° Quadrangle FJ Breakdown into 1° Units


WORLD GEOGRAPHIC REFERENCE SYSTEM (BLUE)

SAMPLE AREA FICTITIOUS

TO REFERENCE TO WITHIN ONE MINUTE

SAMPLE POINT VILLAGE

Read GEOREF values from left to right and from bottom to top
1 Read letters identifying basic 15° quadrangle in which the point lies — MH
2 Read letters identifying 1° quadrangle in which the point lies — AB
3 Locate first MINUTE tick of LONGITUDE to LEFT of point and determine GEOREF value — 12
4 Locate first MINUTE tick of LATITUDE BELOW point and determine GEOREF value — 06

SAMPLE REFERENCE MHAB1206

Figure 3-40. GEOREF Sample Reference

- If references of greater accuracy than one minute are required, each one-minute quadrangle may be further subdivided into decimal parts eastward and northward. Four letters and six figures define a location to 1/10th part of a minute; four letters and eight figures to 1/100th part of a minute, etc.

A reference box is required on all charts over printed by the GEOREF. This box illustrates the standard reference procedure by a fictitious example (see figure 3-40).

Sample Reference. A GEOREF reference consists of all letters and number characters arranged in right and up reading order and largest to smallest area sequence. References are written and read as a continuous series of characters without spaces or punctuation. For example, FJQH-1256, is the standard reference that identifies the southwest corner of the town of Potosi, Missouri. The procedure for locating this point, shown in figure 3-41, is as follows:

- FJ—identifies the basic 15° quadrangle in which the point lies.
- QH—identifies the 1° quadrangle in which the point lies.
- 12—identifies the first minute of longtitude to left of the point. (This value is read from left to right.)
- 56—identifies the first minute of latitude below

the point. (This value is read from bottom to top.)

SPECIAL REFERENCING PROBLEMS. In addition to making basic area references, it is often necessary in air operations to indicate large areas and altitude. Adaptations of the World Geographic Reference System with respect to these requirements follow.

To designate a rectangular or square area other than the basic area referred to in the World Geographic Reference System, the following procedure is used:

1. Read the GEOREF coordinates of the southwest corner of the area.
2. Immediately following the GEOREF coordinates, add the letter "S" denoting "side".
3. Add digits defining the west to east extent of the area in nautical miles.
4. Add the letter "X" denoting "multiplied by".
5. Add digits defining the south to north extent of the area in nautical miles.
6. The designation of the rectangular area in figure 3-42 is EJQK2015S10X12.

To designate a circular area, reference its center by normal GEOREF coordinates, add the letter "R" denoting "radius" and digits defining the radius in nautical miles. Thus, the designation of the circular area in figure 3-42 is EJQK4550R12.

An altitude reference is designated by the letter "H" denoting "height" followed by digits, such as "H10." Two digits indicate thousands of feet, the most common reference. Should greater precision be required, use three digits to indicate hundreds, four digits to indicate tens, and five digits to indicate units of feet.

To designate Greenwich time, the letter "Z" is used, followed by two or four digits representing hours or hours and minutes of the twenty-four hour clock.

Summary

The UTM, UPS, and GEOREF systems are all designed to facilitate location of definite points on the earth's surface. They are used primarily when other conventional systems are difficult to use. The various grid systems used for position location should not be confused with the grid directional system. Grid directional overlays are used in polar navigation. The primary purpose of a grid directional system is to establish a reference direction with regard to some point other than the North Pole. A full explanation of the construction and use of the grid directional overlay is given in the chapter on Grid Navigation.

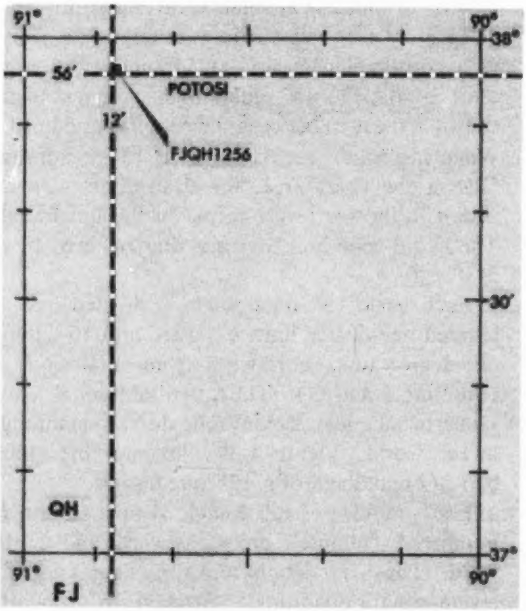


Figure 3-41. To Locate FJQH1256, Interpolate for 12 and 56

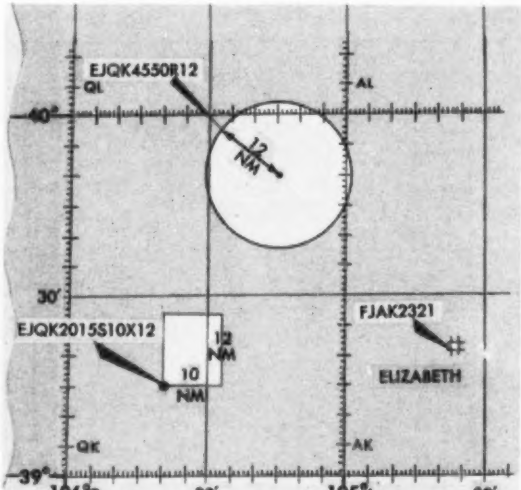


Figure 3-42. Examples of GEOREF Coordinates

Name and Code	Projection	Scale and Coverage	Description	Purpose
USAF Jet Navigation Charts JN	Charts 4, 5, 6 & 7 transverse Mercator. All other Lambert	1:2,000,000 Northern Hemisphere	Charts show all pertinent hydrographic and cultural features. Complete transportation network in areas surrounding cities. A maximum of radar-significant detail as required for long range navigation and a suitable aeronautical information overprint including runway pattern.	For preflight planning and enroute navigation by long range, high speed aircraft; for radar, celestial, and grid navigation. This series can also be used for navigation at medium speeds and altitudes.
Operational Navigation Charts ONC	0°-80° Lambert conformal conic 80°-90° polar stereographic	1:1,000,000 World-wide	Charts show all types hydrographic and cultural features. All important navigation aids and air facilities are included.	Standard series of aeronautical charts designed for military low altitude navigation. Also used for planning intelligence briefings, plotting, and wall displays. (Replaces WAC.)
Tactical Pilotage Charts TPC	0°-80° Lambert conformal conic 80°-90° polar stereographic	1:500,000 World-wide	Charts show all types hydrographic and cultural features. All important navigation aids and air facilities are included.	To provide charts with detailed ground features significant to visual and radar low level navigation for immediate ground/chart orientation at predetermined checkpoints.
Joint Operations Graphic Air Series 1501AIR Formerly JOG (A)	Latitude 84° N to 80° S, Transverse Mercator Latitude 84° to 90° N and 80° to 90° S, Polar-Stereographic	1:250,000 World-wide	Charts show all types hydrographic and cultural features. All important navigation aids and air facilities are included.	To provide Army, Navy, Air Force with a common large-scale graphic. Used for tactical air operations, close air support, interdiction by all aircraft at low and very low altitudes. Used for preflight planning and inflight navigation for short range flights using DR and visual pilotage. Also used for operational planning and intelligence briefing.
Consol-Loran Navigation Charts CJC LJC	Transverse Mercator and Lambert conformal conic	1:2,000,000 Northern Europe and Arctic	Show land areas in subdued tone. Consol, Loran and radio aids are emphasized.	Long range flight planning and electronic navigation.
Air Navigation Charts V 30	Mercator, except Antarctic-Polar Stereographic	1:2,188,800 World-wide with relating Arctic coverage	Charts contain essential topographical, hydrographical, and aeronautical information. Primary roads and railroads are shown.	Basic long range air navigation plotting series designed primarily for use in larger aircraft.
Air/Surface Loran Navigation Charts VL 30 VLC 30	Mercator	1:2,188,800 World-wide with relating Arctic coverage	Contain essential topographical, hydrographical, and aeronautical information. Roads and railroads not shown. Land areas are tinted.	Basic long range Loran air navigation, designed primarily for over water.
Special Navigation Charts VS	Mercator	1:750,000 to 1:4,000,000 Special areas	Charts show essential hydrographic and cultural features. Roads and major railroads are shown. Important air facilities included.	Designed for general air navigation.
Gnomonic Tracking Charts GT	Gnomonic	Various scales From North Pole to approximately 40° South Latitude	Majority are 2-color outline charts with blue for graticule and buff for all land areas. Majority of charts are overprinted with special airways and air communication services.	Series of plotting charts suitable for accurate tracking of aircraft by electronic devices and small scale plotting charts for accurate great circle courses.

Figure 3-43. Summary of Typical Charts

Name and Code	*Projection*	*Scale and Coverage*	*Description*	*Purpose*
Continental Entry Charts CEC	Lambert conformal conic	1:2,000,000 East and West Coasts of U.S.	Show principal cities and hydrography. Show major aeronautical facilities and spot evaluations.	For Consolan and Loran navigation where a high degree of accuracy is required for entry into the U.S. Also suitable as a basic DR sheet and celestial navigation.
USAF Loran-C Navigation Charts LCC	Transverse	1:3,000,000 North Polar areas	Relief not shown. Show major cities and stable aeronautical information. Polar Grid overprint.	For preflight and inflight long range navigation where Loran-C is the basic aid.
USAF Global Loran Navigation Charts GLC	Polar Chart—Transverse Mercator Lower Latitudes—Lambert conformal conic	1:5,000,000 World-wide	Major cities and stable aeronautical information shown. No relief shown.	For inflight long range navigation using Loran and Consol.
USN/USAF Plotting Sheets VP 30	Mercator	1:2,187,400 70° North to 70° South Latitude	Projection graticule only.	To provide uncluttered universal plotting sheets of suitable scope for long range Dead Reckoning and Celestial navigation for selected bands of latitudes.
USAF Global Navigation and Planning Charts GNC	Polar Chart—Transverse Mercator Lower Latitudes—Lambert conformal conic	1:5,000,000 World-wide	Show spot evalautions, major cities, roads, principal hydrography, and stable aeronautical information.	Long distance operational planning. Also suitable for long range inflight navigation at high altitudes and speeds.

Figure 3-43. Summary of Typical Charts (continued)

CHAPTER 4

Basic Instruments

Instruments mechanically measure physical quantities or properties with varying degrees of accuracy. Much of a navigator's work consists of applying corrections to the indications of various instruments and interpreting the results. The navigator must be familiar with the capabilities and limitations of the instruments available to him.

An air navigator obtains the following flight information from basic instruments:

- Direction
- Altitude
- Temperature
- Speed

In this section, some of the basic instruments are discussed. The more complex instruments which make accurate, long distance navigation possible are discussed in later chapters.

DIRECTION

Directional information is needed to navigate in the earth's atmosphere. It is obtained by use of the earth's magnetic lines of force. A compass system uses a device which detects and converts the energy from these lines of force to an indicator reading. The magnetic compass, one of the first to convert magnetic lines of force to directional information, operates independently of the aircraft electrical systems. Later developed compass systems require electrical power to convert these lines of force to an aircraft heading. To use the magnetic compass or the magnetic compass system effectively, the navigator must be familiar with the principles of magnetism.

Magnetism

It has long been known that certain substances have the power to attract pieces of iron. As early as 600 B. C., Thales of Miletus, a Greek philosopher, is supposed to have described the property of a lodestone, a natural magnetic oxide of iron found in many localities.

When a needle of lodestone or magnetized iron is pivoted at its midpoint, it rotates until one end points in a northerly direction. Since the same end of the needle always points north, it is called the north-seeking end or north pole of the "magnet." The other end of the needle is called the south pole. Thus, a magnetized needle, free to turn in the horizontal plane, becomes a simple compass. When two magnets are held near each other, the north pole of one repels the north pole and attracts the south pole of the other. Hence, the rule: Like poles repel, unlike poles attract. (See Figure 4-1.)

Earth's Magnetic Field

The earth has some of the properties of a bar magnet; however, its magnetic poles are not located

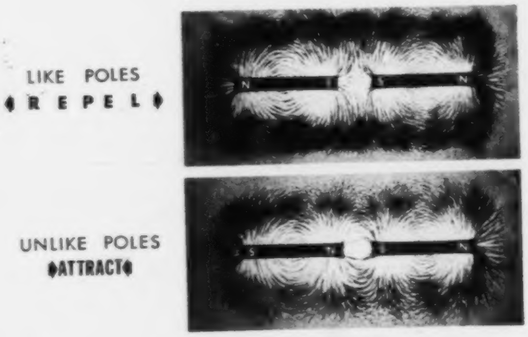


Figure 4-1. Magnetic Force has Direction and Strength

at the geographic poles, nor are the two magnetic poles located exactly opposite each other as on a straight bar. The north magnetic pole is located approximately at latitude 73°N and longitude 100°W, on Prince of Wales Island. The south magnetic pole is located at latitude 68°S and longitude 144°E, on Antarctica.

The earth's magnetic poles, like those of any magnet, can be considered to be connected by a number of lines of force. These lines result from the magnetic field which envelops the earth. They are considered to be emanating from the south magnetic pole and terminating at the north magnetic pole as illustrated in figure 4-2. These lines of force are indicated by the direction that a tiny bar magnet assumes when it is free to rotate in the earth's magnetic field.

A magnetized needle, being restricted of movement by the earth's magnetic field, would point along a line called the magnetic meridian. If the earth were perfectly symmetrical and magnetically homogeneous, its magnetic poles would be 180 degrees apart and its magnetic meridians would be great circles joining these poles. This is not the case, however, and the magnetic meridians form irregular curves.

The force of the magnetic field of the earth can be divided into two components: the vertical and the horizontal. The relative intensity of these two components varies over the earth so that, at the magnetic poles, the vertical component is at maximum strength and the horizontal component is minimum. At approximately the midpoint between the poles, the horizontal component is at maximum strength and the vertical component is minimum. Only the horizontal component is used as a directive force for a magnetic compass. Therefore, a magnetic compass loses its usefulness in an area of weak horizontal force such as the areas around the magnetic poles.

The vertical component causes the end of the needle nearer a magnetic pole to tip as the pole is approached (figure 4-2). This departure from the horizontal is called "magnetic dip."

COMPASSES

A compass may be defined as an instrument which indicates direction over the earth's surface

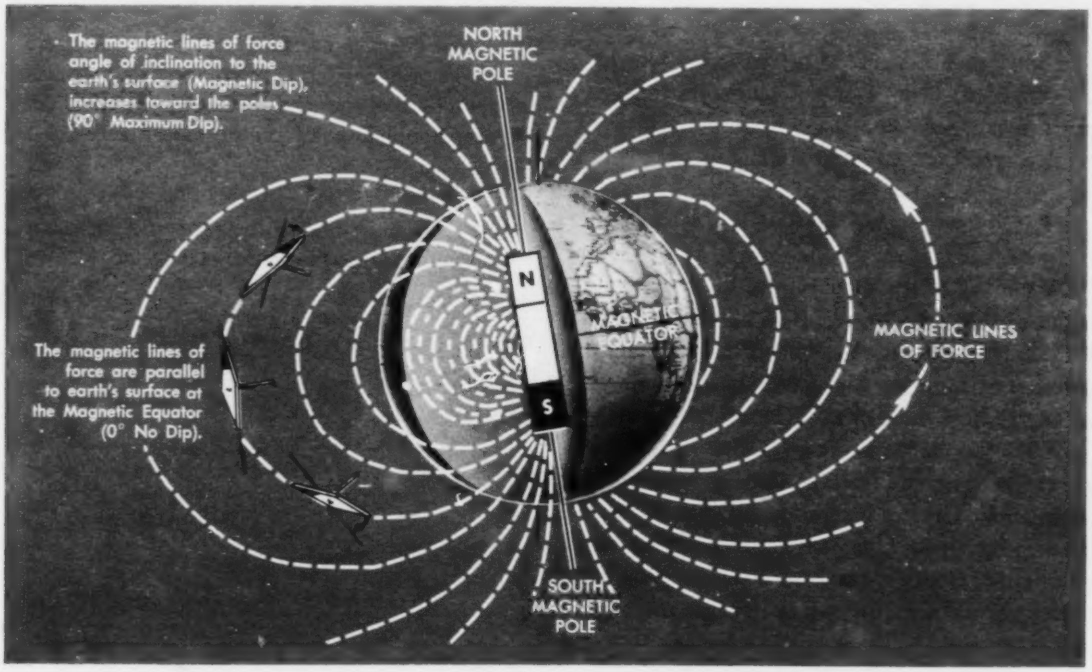

The magnetic lines of force angle of inclination to the earth's surface (Magnetic Dip), increases toward the poles (90° Maximum Dip).
NORTH MAGNETIC POLE
N
MAGNETIC EQUATOR
S
MAGNETIC LINES OF FORCE
The magnetic lines of force are parallel to earth's surface at the Magnetic Equator (0° No Dip).
SOUTH MAGNETIC POLE

Figure 4-2. Earth's Magnetic Field Compared to a Bar Magnet

with reference to a known datum. Various types of compasses have been developed, each of which is distinguished by the particular datum used as the reference from which direction is measured. Two basic types of compasses are in current use.

The magnetic compass uses the lines of force of the earth's magnetic field as a primary reference. Even though the earth's field is usually distorted by the presence of other local magnetic fields, it is the most widely used directional reference.

The gyrocompass uses as its datum an arbitrary fixed point in space determined by the initial alignment of the gyroscope axis. Compasses of this type are widely used today and may eventually replace the magnetic compass entirely.

Magnetic Compass

The magnetic compass is an instrument which indicates direction in the horizontal plane with reference to the horizontal component of the earth's magnetic field. This field is made up of the earth's magnetic field in combination with other magnetic fields in the vicinity of the compass. These secondary magnetic fields are caused by the presence of ferromagnetic objects, etc. Magnetic compasses may be divided into two classes. These are:

1. The direct-indicating magnetic compass in which the measurement of direction is made by a direct observation of the position of a pivoted magnetic needle.
2. The remote-indicating gyro-stabilized magnetic compass in which the magnetic direction is sensed by an element located at positions where local magnetic fields are at a minimum, such as the wing tips. The direction is then transmitted electrically to repeater indicators on the instrument panels.

Direct-Indicating Magnetic Compass. Basically, the magnetic compass is a magnetized rod pivoted at its middle, but several features have been incorporated in design to improve its performance. One type of direct indicating magnetic compass, the B-16 compass, often called the pilot's compass, is illustrated in figure 4-3. It is used as a standby compass in case of failure of the electrical system that operates the remote compasses. It is a reliable compass and will give good navigational results if used carefully. There are two parts of this compass that are important to the navigator, the compass card and the lubber line.

The card is mounted in a bowl filled with a good quality damping fluid. The damping fluid partially floats the card, thereby taking some of the weight off the pivot that supports it. The fluid also decreases the oscillation of the needle and lubricates the pivot. The magnets are mounted on the card which remains aligned with magnetic north as the aircraft turns about it. A compass rose, graduated in 1-degree intervals on some models and in 5-degree intervals on other models,

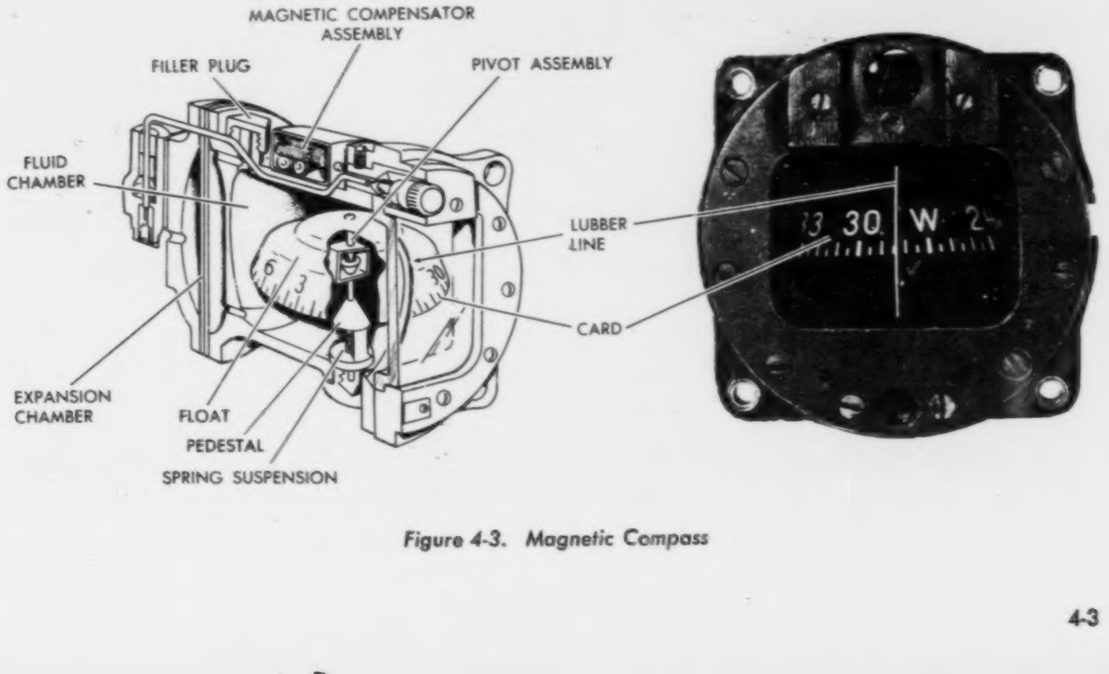


Figure 4-3. Magnetic Compass

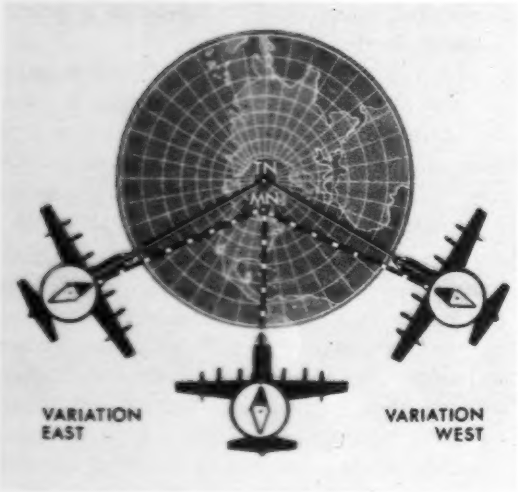

TN
MN
VARIATION EAST
VARIATION WEST

Figure 4-4. Variation is Angle Between True North and Magnetic North

is attached to the card. On the reverse side of the compass (the side toward the tail of the aircraft) there is a glass window through which the compass is read. Down the center of the window there is a lubber line corresponding to the longitudinal axis of the aircraft. Since the card is read from the reverse side, it is necessary that it be numbered with 180-degree ambiguity to give proper readings.

Concealed in the compass on the opposite side from the window is an expansion-contraction cell to take care of expansion of the liquid under different temperatures. On top of the compass case there are two small magnets that can be rotated in relation to the compass to counteract deviation.

Magnetic Compass Errors. It has been stated that the earth's magnetic poles are joined by irregular curves called magnetic meridians. The angle formed at any point between the magnetic meridian and the geographic meridian is called the magnetic variation. Variation is listed on the charts as east or west. When variation is east, magnetic north is east of true north. Similarly, when variation is west, magnetic north is west of true north (figure 4-4). Lines connecting points having the same magnetic variation are called isogonic lines, as shown in figure 4-5. Magnetic variation is an error which must be corrected if a compass indication is to be converted to true direction.

Another error with which the navigator is con-

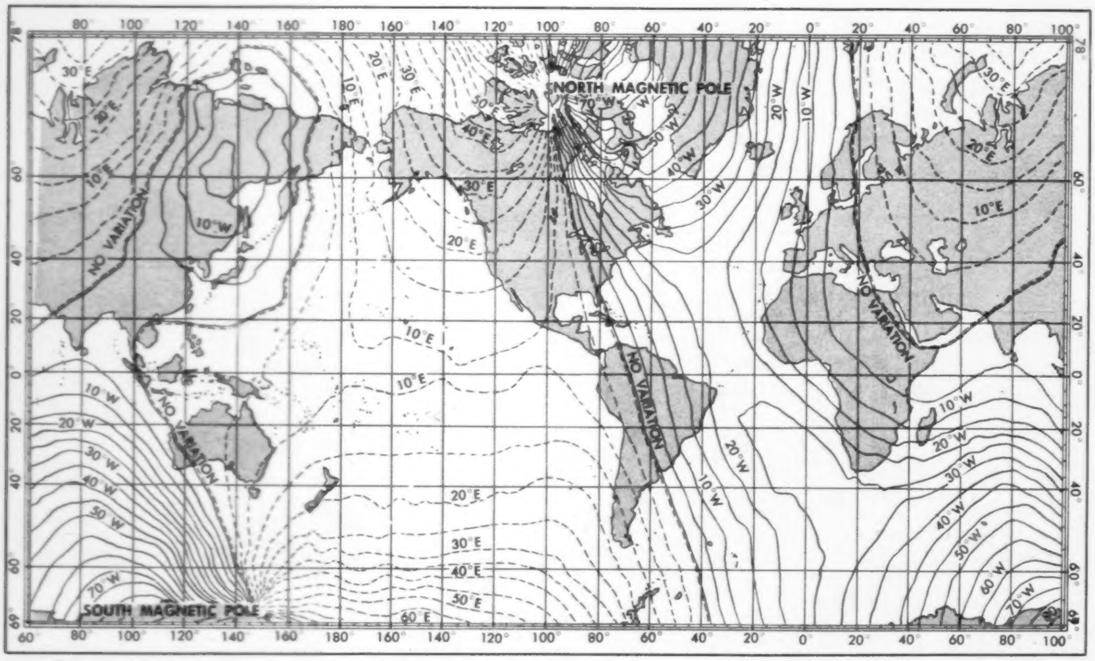

NORTH MAGNETIC POLE
SOUTH MAGNETIC POLE
NO VARIATION
NO VARIATION
NO VARIATION
NO VARIATION
30°E
20°E
10°E
10°W
20°W
30°W
40°W
50°W
60°W
70°W
40°E
50°E
60°E
80° 100° 120° 140° 160° 180° 160° 140° 120° 100° 80° 60° 40° 20° 0° 20° 40° 60° 80° 100°
78 60 40 20 0 20 40 60 69

Figure 4-5. Isogonic Lines Show Same Magnetic Variation

cerned is caused by nearby magnetic influences, such as those related to magnetic material in the structure of the aircraft and its electrical systems. These magnetic forces deflect a compass needle from its normal alignment with a magnetic meridian. The amount of such deflection is called deviation, which, like variation, is labeled east or west as the north-seeking end of the compass is deflected east or west of magnetic north, respectively.

The correction for variation and deviation is usually expressed as a plus or minus value and is computed as a correction to true heading. If variation or deviation is east, the sign of the correction is minus, and if west, the sign is plus. A rule of thumb for this correction is easily remembered as *East is least and West is best.*

Aircraft headings are expressed in various ways, according to the basic reference for the heading. If the heading is measured in relation to geographical north, it is a true heading. If the heading is in reference to magnetic north, it is a magnetic heading, and if it is in reference to the compass lubber line, it is a compass heading. Compass heading differs from true heading by the amount of variation and deviation encountered. Magnetic heading varies from true heading by the amount of variation.

This relationship is best expressed by reference to AF Form 21, Navigator's Log, where the various headings and corrections are listed as True Heading (TH), Variation (Var), Magnetic Heading (MH), Deviation (Dev), Compass Heading (CH). Thus, if an aircraft is flying in an area where the variation is 10°E and the compass has a deviation of 3°E, the relationship would be expressed as follows, assuming a compass heading 125 degrees:
(figure 4-6)

TH	Var	MH	Dev	CH
138 —	10 =	128 —	3 =	125

Variation. Variation has been measured at a great many places throughout the world, and the values so found have been plotted on charts. For convenience, isogonic lines have been drawn through all points having the same variation. Figure 4-5, Isogonic Lines, is a simplified chart showing world-wide coverage of variation. Isogonic lines are printed on most charts used in aerial navigation so that, if a navigator knows his approximate position, he can determine the amount of variation by visual interpolation between the printed lines. These values are almost directly proportional in accuracy to the cube of the aircraft altitude above the ground. At high altitudes these values can be considered quite realistic. Conversely, at low altitudes these magnetic values are less reliable because of local anomalies.

Variation changes slowly over a period of years and the yearly amount of such change is printed on most charts. Variation is also subject to small diurnal (daily) changes which may generally be neglected in air navigation.

Deviation. Since deviation depends upon the distribution of magnetic forces in the aircraft itself, it must be obtained individually for each magnetic compass on each aircraft. The process of determining deviation, known as compass swinging, is

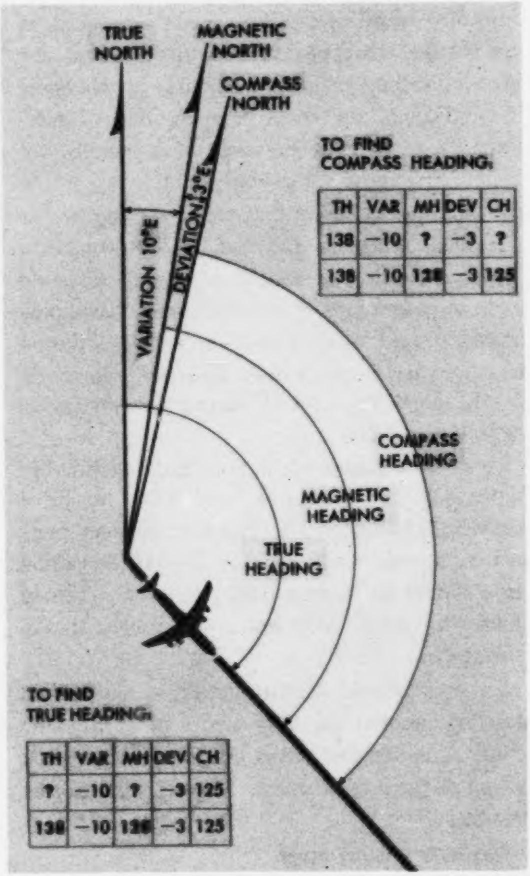


Figure 4-6. To Find True Heading, Work Backwards

fully discussed in the technical order for each compass.

Deviation changes with heading as shown in figure 4-7. Suppose the net result of all inherent magnetic forces of the aircraft (those forces excluding the earth's field) is represented by a dot in the longitudinal axis located just behind the wings of the aircraft. If the aircraft is headed toward magnetic north, the dot attracts one pole of the magnetic compass (in this case, the south pole), but on this heading does not change its direction. The only effect is to amplify the directive force of the earth's field. Suppose now that the aircraft heads toward magnetic east. The illustration in figure 4-7 shows that the dot is now west of the compass, in which position it attracts the south pole of the compass and repels the north pole, causing easterly deviation. The illustration in figure 4-7 also shows that the deviation is zero on a south heading, and westerly when the aircraft is heading west. Deviation can be reduced in some of the more basic compasses, such as the direct-indicating magnetic compass, by changing the position of the small compensating magnets in the compass case; however, it is usually not possible to remove all of the deviation on all the headings. The deviation that remains is referred to as residual deviation and can be determined by comparison with true values. After such deviation has been determined, it is recorded on a compass correction card which shows the actual deviation on various headings, or more frequently, the compass headings for various magnetic headings as illustrated in figure 4-8.

From the compass correction card illustrated in Figure 4-8, the navigator knows that to fly a magnetic heading of 270 degrees, the pilot must steer a compass heading of 268 degrees. Deviation cards should be mounted near the compasses to which they refer, with copies convenient to the navigator.

Errors in Flight. Unfortunately, variation and deviation are not the only errors of a magnetic compass. Additional errors are introduced by the motion of the aircraft itself. These errors may be classified as:

- Northerly turning error.
- Speed error.
- Heeling error.
- Swirl error.
- Yaw error.

Northerly turning error is maximum during a turn from a north or a south heading, and is caused by the action of the vertical component of the earth's field upon the compass magnets. When the aircraft is in straight and level flight, the compass card is balanced on its pivot in approximately a horizontal position. In this position, the vertical component of the earth's field is not effective as a directive force. When the aircraft is banked, however, the compass card banks too, as a result of the centrifugal force acting on it. While the compass card is in this banked attitude in northern latitudes, the vertical component of the earth's magnetic field causes the north-seeking end of the compass to dip to the low side of the turn, giving the pilot an erroneous turn indication. In effect, the north-seeking end of the needle reacts as though it is weighted and dips toward the low wing. This error, called northerly turning error, is most apparent on headings of north and south. In a turn from a heading of north, the compass briefly gives an indication of a turn in the opposite direction; in a turn from a heading of south, it gives an indication of a turn in the proper direction but at a more rapid rate than is actually the case (see figure 4-9). In southern latitudes, all these errors are reversed. They are called southerly

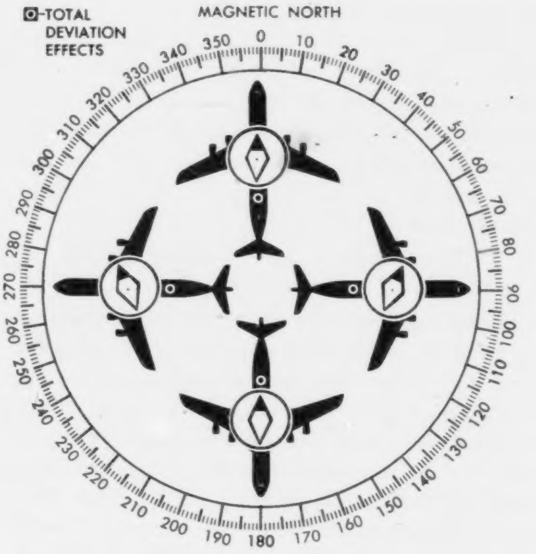
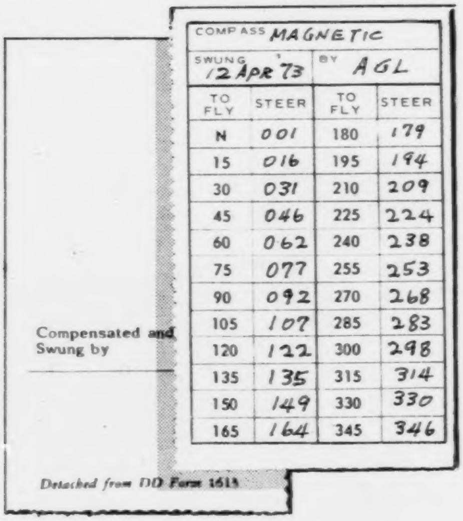


Figure 4-7. Deviation Changes with Heading



COMPASS MAGNETIC			
SWUNG 12 APR 73		BY AGL	
TO FLY	STEER	TO FLY	STEER
N	001	180	179
15	016	195	194
30	031	210	209
45	046	225	224
60	062	240	238
75	077	255	253
90	092	270	268
105	107	285	283
120	122	300	298
135	135	315	314
150	149	330	330
165	164	345	346

Compensated and Swung by

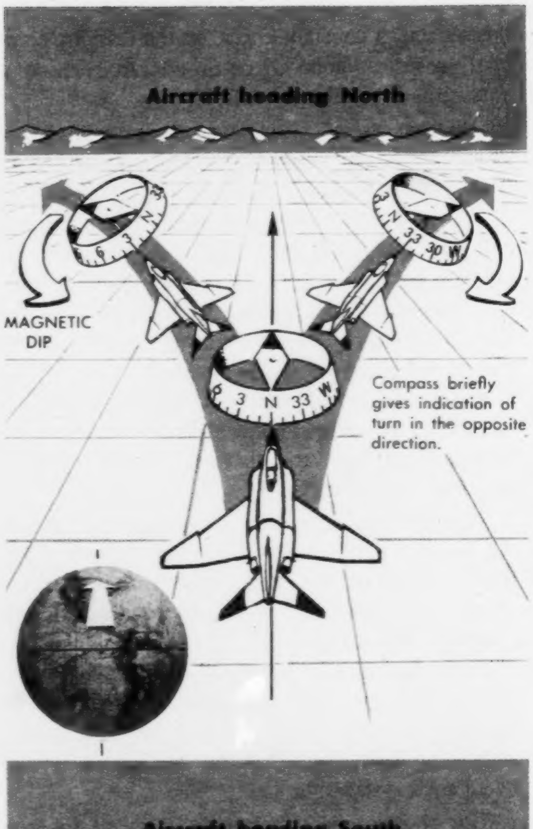
Detached from DD Form 1613

Figure 4-8. Compass Correction Card

turning error. It is apparent that precise turns are difficult by reference to such a compass. This error can be virtually eliminated by reference to a gyro stabilized system.

If an aircraft flying an east or west heading changes speed, the compass card tends to tilt forward or backward. The vertical component then has an effect as in a turn, causing an error which is like northerly turning error but is known as speed error. If an aircraft is flying straight but in a banked attitude, a heeling error may be introduced because of the changed position, with respect to the compass magnets, of the small compensating magnets in the case and other magnetic fields within the aircraft. The heading on which heeling error is maximum depends upon the particular situation. Swirl error may occur when the liquid within the compass case is set in motion during a turn. Finally, yaw error may occur if a multi-engined aircraft is yawing about its vertical axis due to difference in power settings of the engines.

Although a basic magnetic compass, such as the B-16 or standby compass, has numerous shortcomings, it is simple and reliable. The compass is very useful to both the pilot and navigator and is carried on all aircraft as an auxiliary compass. Since most modern compass systems are dependent upon the electrical system of the aircraft, a loss of power means a loss of the compass system. For



Compass briefly gives indication of turn in the opposite direction.

Compass indicates turn in correct direction but at a faster rate than actually being turned.

Figure 4-9. Compass Card in Normal and Banked Positions

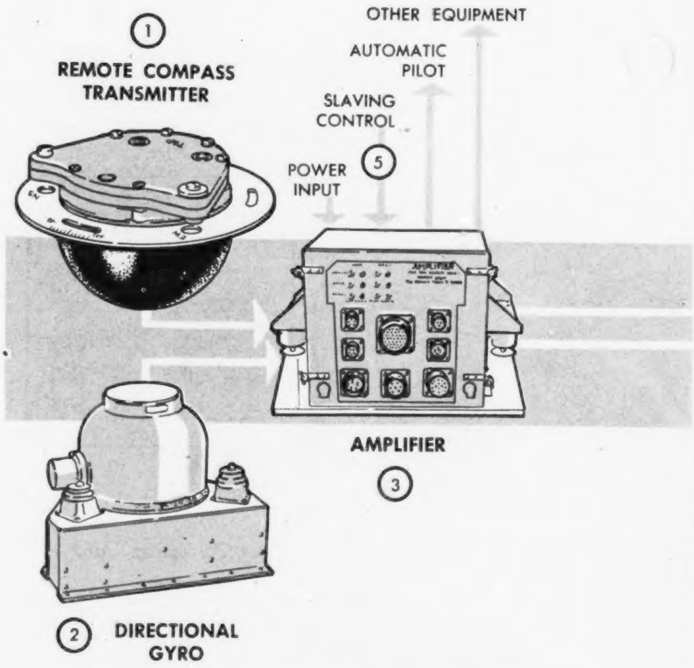
this reason, a constant check on the standby compass provides a good check on the electrical compass systems of the aircraft.

Remote Indicating Gyro-Stabilized Magnetic Compass System. A chief disadvantage of the simple magnetic compass is its susceptibility to deviation. In remote-indicating gyro-stabilized compass systems, this difficulty is overcome by locating the compass direction-sensing device outside magnetic fields created by electrical circuits in the aircraft. This is done by installing the direction-sensing device in a remote part of the aircraft such as the outer extremity of a wing. Indicators of the compass system can then be located throughout the aircraft without regard to magnetic disturbances.

Several kinds of compass systems are used in Air Force aircraft. All include the following five basic components: (1) remote compass transmitter, (2) directional gyro, (3) amplifier, (4) heading indicators, and (5) slaving control. Though the names of these components vary among systems, the principle of operation is identical for each. Thus the N-1 compass system shown in figure 4-10 can be considered typical of all such systems.

The N-1 compass system is designed for airborne use at all latitudes. It can be used either as a magnetic slaved compass or as a directional gyro. In addition, the N-1 generates an electric signal which is used as an azimuth reference by the autopilot, the radar system, the navigation and bombing computers, and the radio magnetic indicator.

Remote Compass Transmitter. The remote compass transmitter is the "magnetic-direction-sensing" component of the compass system when the system is in operation as a magnetic-slaved compass. The transmitter is located as far from magnetic disturbances of the aircraft as possible, usually in a wing tip or the vertical stabilizer. The transmitter senses the horizontal component of the earth's magnetic field (the only component of any value for directional purposes) and electrically transmits it to the master indicator. The compensator, an auxiliary unit of the remote compass transmitter, is used to eliminate most of the magnetic deviation caused by aircraft electrical equipment and ferrous metal, when a deviation-free location for the remote compass transmitter is not available.



Directional Gyro. The directional gyro is the stabilizing component of the compass system when the system is in magnetic-slaved operation. When the compass system is in directional-gyro operation, the gyro acts as the directional reference component of the system.

Amplifier. The amplifier is the receiving and distributing center of the compass system. Azimuth correction and leveling signals originating in the components of the system are each received, amplified, and transmitted by separate channels in the amplifier. Primary power to operate the compass is fed to the amplifier and distributed to the system's components.

Master Indicator. The master indicator is the heading indicating component of the compass system. The mechanism in the master indicator integrates all data received from the directional gyro and the remote compass transmitter, corrects the master indicator heading pointer for azimuth drift of the directional gyro due to the earth's rotation, and provides take-off signals for operating remote indicators, radar, and directional control of the auto pilot.

The latitude correction control knob at the upper right-hand corner of the master indicator face provides a means for selecting either mag-

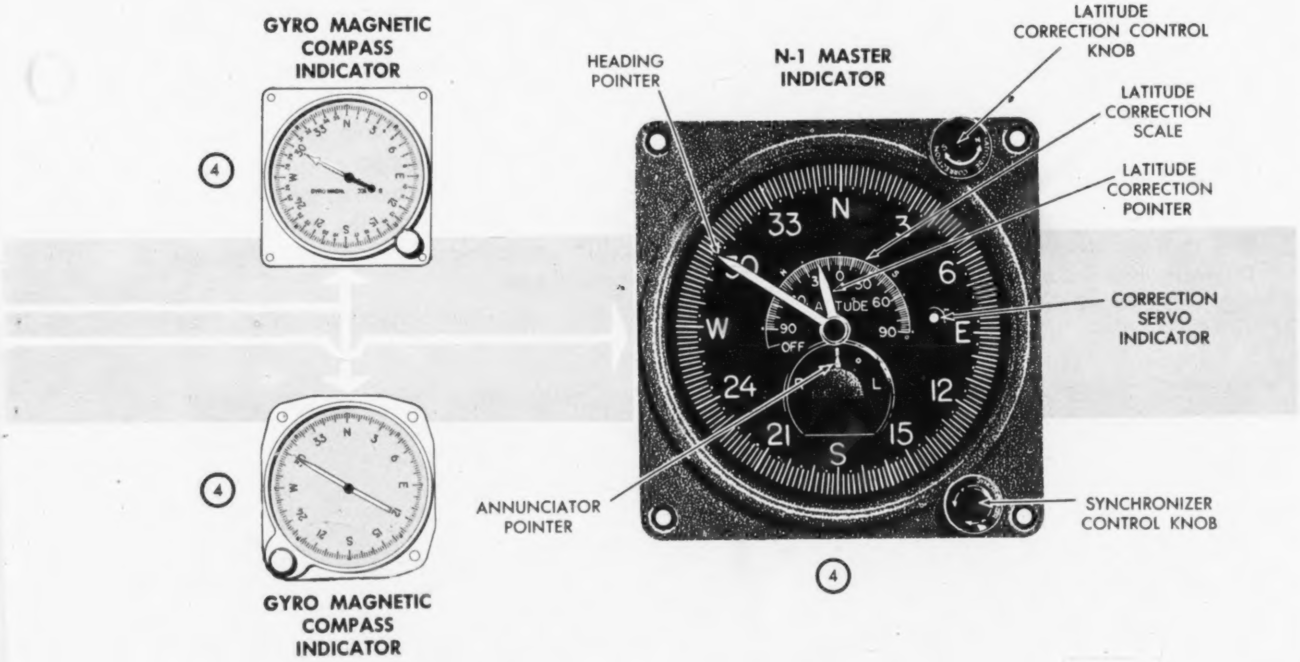

GYRO MAGNETIC COMPASS INDICATOR
④
HEADING POINTER
N-1 MASTER INDICATOR
LATITUDE CORRECTION CONTROL KNOB
LATITUDE CORRECTION SCALE
LATITUDE CORRECTION POINTER
CORRECTION SERVO INDICATOR
④
GYRO MAGNETIC COMPASS INDICATOR
ANNUNCIATOR POINTER
SYNCHRONIZER CONTROL KNOB
④

Figure 4-10. N-1 Compass System Components

netic-slaved operation or directional-gyro operation of the compass system as well as the proper latitude correction rate.

The latitude correction pointer is mechanically connected to the latitude correction control knob and indicates the latitude setting on the latitude correction scale at the center of the master indicator dial face.

The synchronizer control knob at the lower right-hand corner of the master indicator face provides a means of synchronizing the master indicator heading pointer with the correct magnetic heading when the system is in magnetic-slaved operation. It also provides a means of setting the master indicator heading pointer on the desired gyro heading reference when the system is in directional-gyro operation.

The annunicator pointer indicates the direction in which to rotate the synchronizer control knob to align the heading pointer with the correct magnetic heading.

A small hole is provided in the right side of the dial face through which the direction of rotation of a white dot, the correction servo indicator, may be observed. The rotating dot indicates that the master indicator is using information from either the latitude-correction mechanism or the remote compass transmitter. In magnetic-slaved operation, the dot will rotate slowly back and forth indicating that the system is constantly integrating information from the remote compass transmitter. In directional-gyro operation, the dot will rotate at a speed proportional to the latitude correction. It will rotate clockwise when north latitude is set and counterclockwise when south latitude is set.

Gyro Magnetic Compass Indicators. The gyro magnetic compass indicators are remote-reading, settable-dial compass indicators. They are intended for supplementary use as directional compass indicators when used with the compass system. The indicators duplicate the azimuth heading of the master indicator heading pointer. A setting knob is provided at the front of each indicator for rotating the dial 360° in either direction without changing the physical alignment of the pointer.

Slaving Control. The slaving control is a gyro-control rate switch which reduces errors in the compass system during turns. When the aircraft turns at a rate of 23° or more per minute, the slaving control prevents the remote compass transmitter signal from being transmitted to the compass system during magnetic-slaved operation. It also interrupts leveling action in the directional gyro when the system is in magnetic-slaved or directional-gyro operation.

The Gyro

Any spinning body exhibits gyroscopic properties. A wheel designed and mounted to use these properties is called a gyroscope or gyro. Basically, a gyro is a rapidly rotating mass which is free to move about one or both axes perpendicular to the axis of rotation and to each other. The three axes of a gyro, namely, spin axis, drift axis, and topple axis shown in figure 4-11 are defined as follows:

- In a directional gyro, the spin axis or axis of rotation is mounted horizontally.
- The topple axis is that axis in the horizontal plane that is 90 degrees from the spin axis.
- The drift axis is that axis 90 degrees vertically from the spin axis.

Gyroscopic drift is the horizontal rotation of the

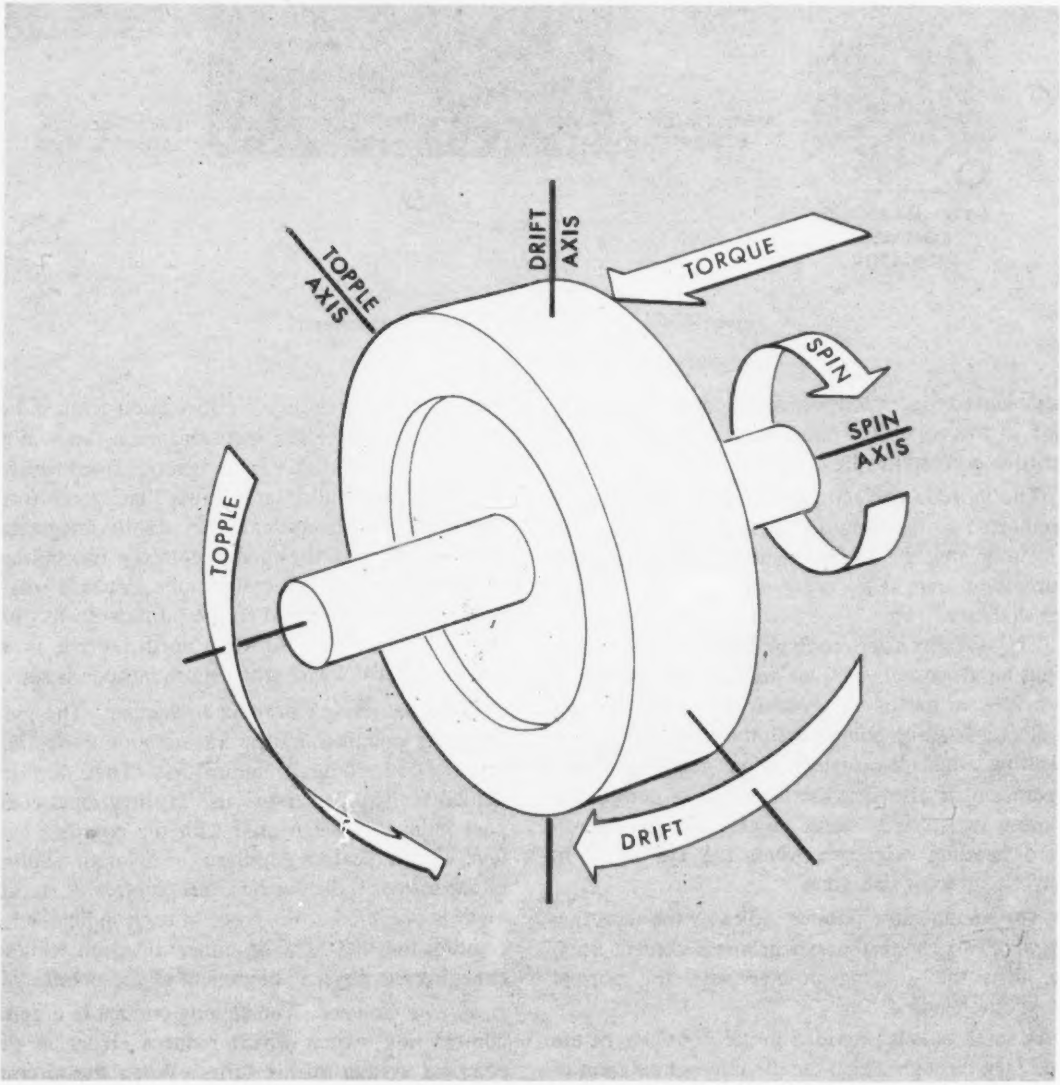


Figure 4-11. Gyroscope Axes

spin axis about the drift axis. Topple is the vertical rotation of the spin axis about the topple axis. These two component drifts result in motion of the gyro called precession.

A freely spinning gyro tends to maintain its spin axis in a constant direction in space, a property known as rigidity in space or gyroscopic inertia. Thus, if the spin axis of a gyro were pointed toward a star, it would rotate at the same rate as the star and keep pointing at the star. Actually, the gyro does not move, but the earth moving beneath it gives it an apparent motion. This apparent motion, shown in figure 4-12, is called apparent precession. The magnitude of apparent precession is dependent upon latitude. The horizontal component, drift, is equal to 15 degrees per hour times the sine of the latitude, and the vertical component, topple, is equal to 15 degrees per hour times the cosine of the latitude.

These computations assume the gyro is sta-

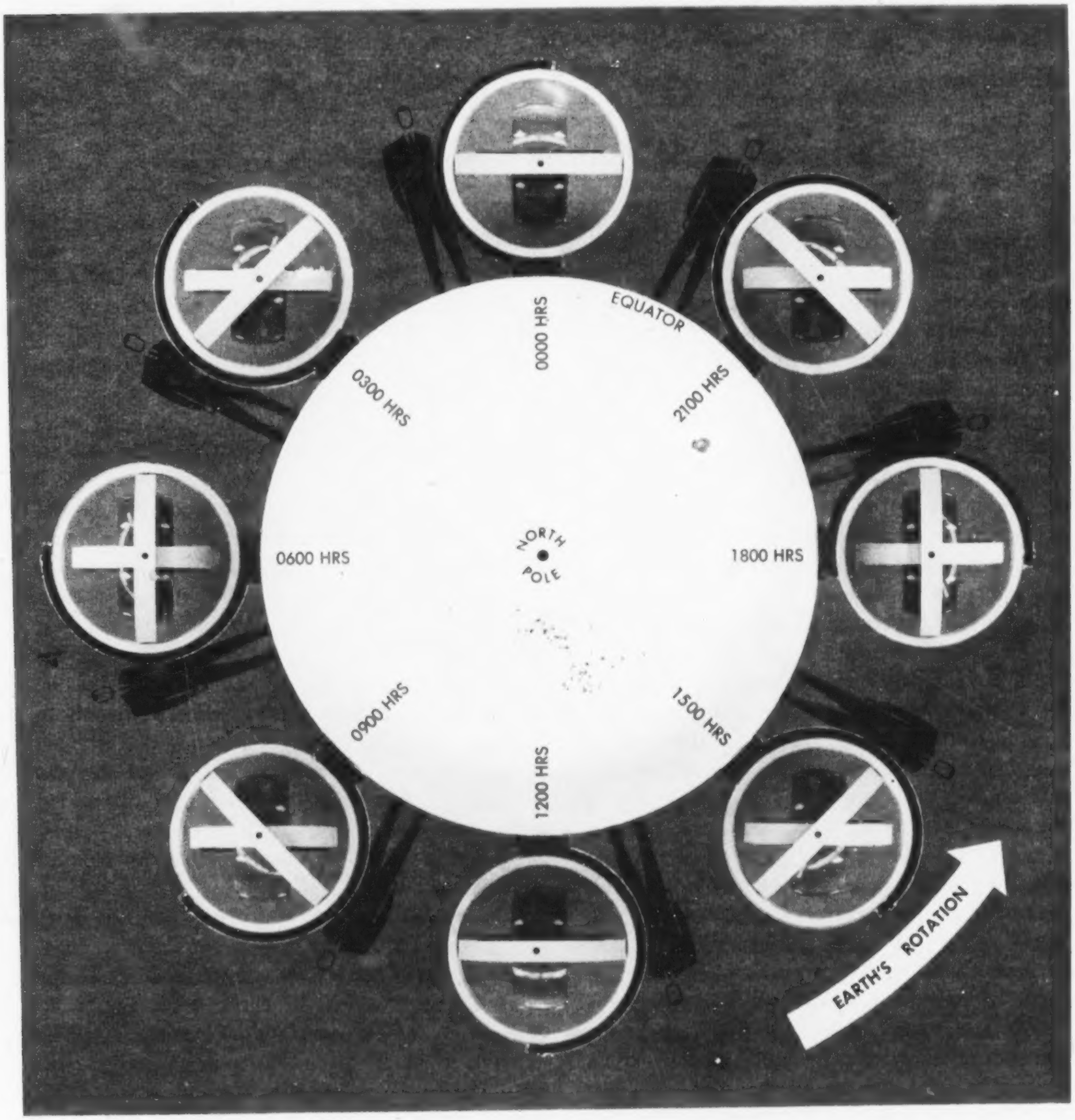
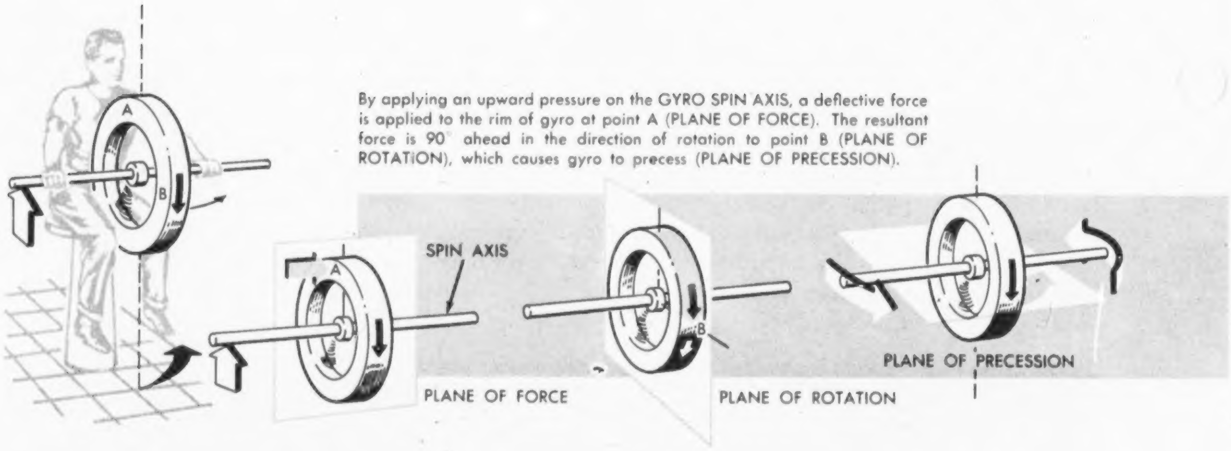


Figure 4-12. Apparent Precession



By applying an upward pressure on the GYRO SPIN AXIS, a deflective force is applied to the rim of gyro at point A (PLANE OF FORCE). The resultant force is 90° ahead in the direction of rotation to point B (PLANE OF ROTATION), which causes gyro to precess (PLANE OF PRECESSION).

Figure 4-13. Precession of Gyroscope Resulting from Applied Deflective Force

tionary with respect to the earth. However, if the gyro is to be used in a high speed aircraft, it is readily apparent that its speed with respect to a point in space may be more or less than the speed of rotation of the earth. If the aircraft in which the gyro is mounted is moving in the same direction as the earth, the speed of the gyro with respect to space will be greater than the earth's speed. The opposite is true if the aircraft is flying in a direction opposite to that of the earth's rotation. This difference in the magnitude of apparent precession caused by transporting the gyro over the earth is called transport precession.

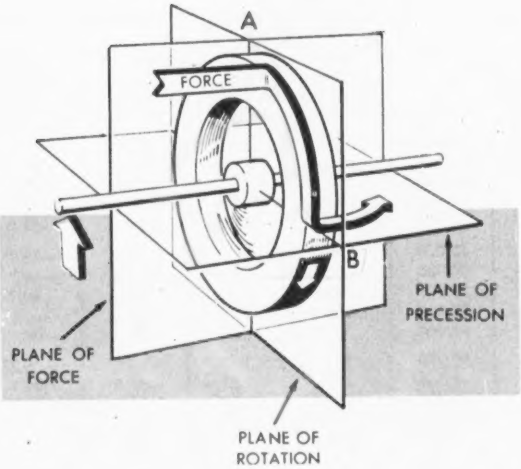
A gyro may precess because of factors other than the earth's rotation. When this occurs, the precession is labeled real precession. When a force is applied to the plane of rotation of a gyro, the plane tends to rotate, not in the direction of the applied force, but 90 degrees around the spin axis from it. This torquing action, shown in figure 4-13, may be used to control the gyro by bringing about a desired reorientation of the spin axis, and most directional gyros are equipped with some sort of device to introduce this force.

However, friction within the bearings of a gyro may have the same effect and cause a certain amount of unwanted precession. Great care is taken in the manufacture and maintenance of gyroscopes to eliminate this factor as much as possible, but, as yet, it has not been possible to eliminate it entirely. Precession caused by the mechanical limitations of the gyro is called real or induced precession. The combined effects of apparent precession, transport precession, and real precession produce the total precession of the gyro.

The properties of the gyro that most concern the navigator are rigidity and precession. By understanding these two properties, the navigator is well equipped to use the gyro as a reliable steering guide.

DIRECTIONAL GYRO. The discussion thus far has been of a universally mounted gyro, free to turn in the horizontal or vertical, or any component of these two. This type of gyro is seldom, if ever, used as a directional gyro. When the gyro is used as a steering instrument, it is restricted so that the spin axis remains parallel to the surface of the earth. Thus, the spin axis is free to turn only in the horizontal plane (assuming the aircraft normally flies in a near level attitude), and only the horizontal component (drift) will affect a steering gyro. In the terminology of gyro steering, precession always means the horizontal component of precession.

The operation of the instrument depends upon the principle of rigidity in space of the gyroscope. Fixed to the plane of the spin axis is a circular compass card, shown in figure 4-14, similar to that of the magnetic compass. Since the spin axis remains rigid in space, the points on the card hold the same position in space relative to the horizontal plane. The case, to which the lubber line is attached, simply revolves about the card.


A
FORCE
B
PLANE OF PRECESSION
PLANE OF FORCE
PLANE OF ROTATION

It is important at this point to understand that the numbers on the compass card have no meaning within themselves, as on the magnetic compass. The fact that the gyro may indicate 100 degrees under the lubber line is not an indication that the instrument is actually oriented to magnetic north, or any other known point. To steer by the gyro, the navigator must first set it to a known direction or point. Usually, this is magnetic north or geographic north, though it can be at any known point. If, for example, magnetic north is set as the reference, all headings on the gyro read relative to the position of the magnetic poles.

The actual setting of the initial reference heading is done by using the principle discussed earlier of torque application to the spinning gyro. By artificially introducing precession, the navigator can set the gyro to whatever heading is desired and can reset it at any time using the same technique.

Gyrocompass Errors. The major error affecting the gyro and its use as a steering instrument is precession. Apparent precession will cause an apparent change of heading equal to 15 degrees per hour times the sine of the latitude. Real precession, caused by defects in the gyro, may occur at any rate. This type of precession has been greatly reduced by the high precision of modern manufacturing methods. Apparent precession is a known value depending upon location and can be compensated for. In some of the more complex

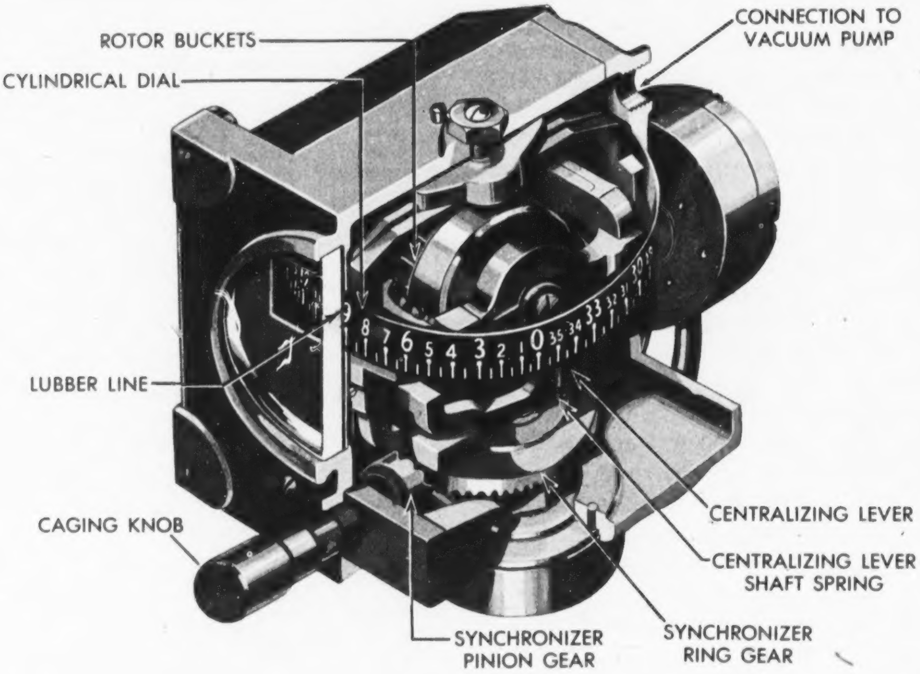

ROTOR BUCKETS
CYLINDRICAL DIAL
CONNECTION TO VACUUM PUMP
LUBBER LINE
CAGING KNOB
CENTRALIZING LEVER
CENTRALIZING LEVER SHAFT SPRING
SYNCHRONIZER PINION GEAR
SYNCHRONIZER RING GEAR

Figure 4-14. Cutaway View of a Directional Gyro

gyro systems such as the N-1 compass system, apparent precession is compensated by setting in a constant correction equal to and in the opposite direction to the precession caused by the earth's rotation.

ALTITUDE AND ALTIMETERS

Altitude may generally be defined as the height of an aircraft above the earth. Knowledge of the aircraft altitude is important for several reasons. To remain a safe distance above dangerous mountain peaks, the navigator must know the altitude of the aircraft and the elevation of the surrounding terrain at all times. This is especially important when visibility is poor and the terrain cannot be seen. Also, it is often desirable to fly a certain altitude to take advantage of favorable winds and weather conditions.

Altitude may be defined as a vertical distance above some point or plane used as a reference. There can be as many kinds of altitude as there are reference planes from which to measure them, but the navigator need concern himself only with six: *indicated altitude, calibrated altitude, pressure altitude, density altitude, true altitude, and absolute altitude.* There are two main types of altimeters; the pressure altimeter which is installed in every aircraft and the absolute or radar altimeter. To understand the pressure altimeter's principle of operation, a knowledge of the standard datum plane is essential.

Standard Datum Plane

The standard datum plane is a theoretical plane where the atmospheric pressure is 29.92 inches of mercury (Hg) and the temperature is +15°C. The standard datum plane is the zero elevation level of an imaginary atmosphere known as the standard atmosphere. In the standard atmosphere, pressure is 29.92″ Hg at 0 feet and decreases upward at the standard pressure lapse rate. The temperature is +15°C at 0 feet and decreases upward at the standard temperature lapse rate. Both the pressure and temperature lapse rates are given in the table in figure 4-15.

The standard atmosphere is theoretical. It was derived by averaging the readings taken over a period of many years. The list of altitudes and their corresponding values of temperature and pressure given in the table were determined by

Altitude (feet)	*Standard pressure (millibars)*	*Standard pressure (inches of mercury)*	*Standard temperature (°C)*	*Standard temperature (°F)*
60,000	71.7	2.12	−56.5	−69.7
59,000	75.2	2.22	−56.5	−69.7
58,000	79.0	2.33	−56.5	−69.7
57,000	82.8	2.45	−56.5	−69.7
56,000	86.9	2.57	−56.5	−69.7
55,000	91.2	2.69	−56.5	−69.7
54,000	95.7	2.83	−56.5	−69.7
53,000	100.4	2.96	−56.5	−69.7
52,000	105.3	3.11	−56.5	−69.7
51,000	110.5	3.26	−56.5	−69.7
50,000	116.0	3.42	−56.5	−69.7
49,000	121.7	3.59	−56.5	−69.7
48,000	127.7	3.77	−56.5	−69.7
47,000	134.0	3.96	−56.5	−69.7
46,000	140.6	4.15	−56.5	−69.7
45,000	147.5	4.35	−56.5	−69.7
44,000	154.7	4.57	−56.5	−69.7
43,000	162.4	4.79	−56.5	−69.7
42,000	170.4	5.04	−56.5	−69.7
41,000	178.7	5.28	−56.5	−69.7
40,000	187.5	5.54	−56.5	−69.7
39,000	196.8	5.81	−56.5	−69.7
38,000	206.5	6.10	−56.5	−69.7
37,000	216.6	6.40	−56.5	−69.7
36,000	227.3	6.71	−56.3	−69.4
35,000	238.4	7.04	−54.3	−65.8
34,000	250.0	7.38	−52.4	−62.2
33,000	262.0	7.74	−50.4	−58.7
32,000	274.5	8.11	−48.4	−55.1
31,000	287.4	8.49	−46.4	−51.6
30,000	300.9	8.89	−44.4	−48.0
29,000	314.8	9.30	−42.5	−44.4
28,000	329.3	9.72	−40.5	−40.9
27,000	344.3	10.17	−38.5	−37.3
26,000	359.9	10.63	−36.5	−33.7
25,000	376.0	11.10	−34.5	−30.2
24,000	392.7	11.60	−32.5	−26.6
23,000	410.0	12.11	−30.6	−23.0
22,000	427.9	12.64	−28.6	−19.5
21,000	446.4	13.18	−26.6	−15.9
20,000	465.6	13.75	−24.6	−12.3
19,000	485.5	14.34	−22.6	−8.8
18,000	506.0	14.94	−20.7	−5.2
17,000	527.2	15.57	−18.7	−1.6
16,000	549.2	16.22	−16.7	1.9
15,000	571.8	16.89	−14.7	5.5
14,000	595.2	17.58	−12.7	9.1
13,000	619.4	18.29	−10.8	12.6
12,000	644.4	19.03	− 8.8	16.2
11,000	670.2	19.79	− 6.8	19.8
10,000	696.8	20.58	− 4.8	23.3
9,000	724.3	21.39	− 2.8	26.9
8,000	752.6	22.22	− 0.8	30.5
7,000	781.8	23.09	1.1	34.0
6,000	812.0	23.98	3.1	37.6
5,000	843.1	24.90	5.1	41.2
4,000	875.1	25.84	7.1	44.7
3,000	908.1	26.82	9.1	48.3
2,000	942.1	27.82	11.0	51.9
1,000	977.2	28.86	13.0	55.4
Sea level	1013.2	29.92	15.0	59.0

Figure 4-15. Standard Lapse Rate Table

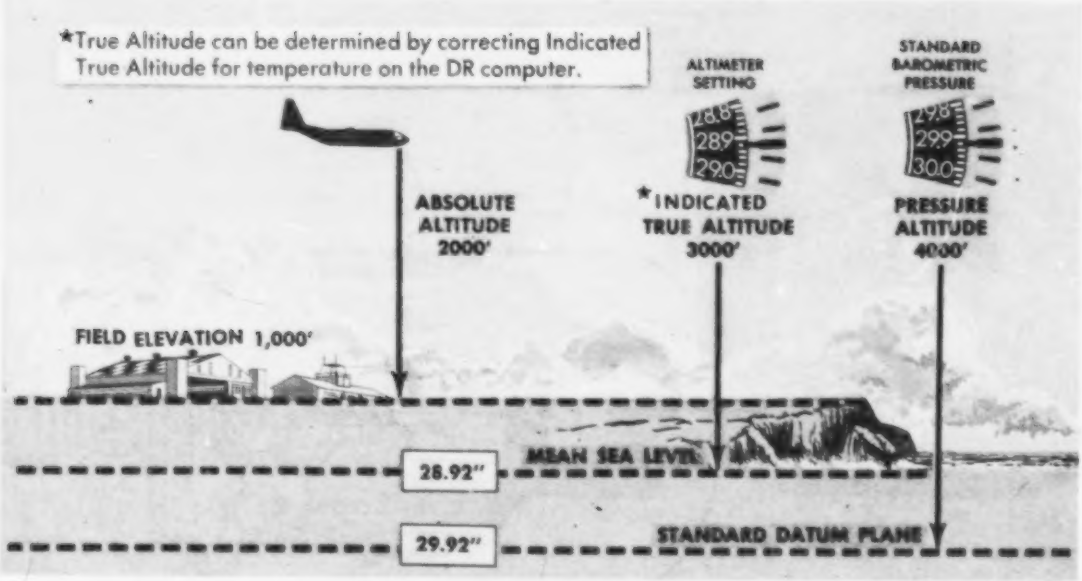

*True Altitude can be determined by correcting Indicated True Altitude for temperature on the DR computer.
ALTIMETER SETTING
STANDARD BAROMETRIC PRESSURE
28.8
28.9
29.0
29.8
29.9
30.0
ABSOLUTE ALTITUDE 2000'
*INDICATED TRUE ALTITUDE 3000'
PRESSURE ALTITUDE 4000'
FIELD ELEVATION 1,000'
MEAN SEA LEVEL
28.92"
29.92"
STANDARD DATUM PLANE

Figure 4-16. Types of Altitude

these averages. The height of the aircraft above the standard datum plane (29.92" Hg and +15°C) is called pressure altitude as illustrated in figure 4-16.

Pressure Altimeter Principle of Operation

The pressure altimeter is an aneroid barometer calibrated to indicate feet of altitude instead of pressure. As shown in figure 4-17, the pointers are connected by a mechanical linkage to a set of aneroid cells. These aneroid cells expand or contract with changes in barometric pressure. In this manner, the cells assume a particular thickness at a given pressure level and thereby position the altitude pointers accordingly. On the face of the altimeter is a barometric scale which indicates the barometric pressure (expressed in inches of mercury) of the point or plane from which the instrument is measuring altitude. Turning the barometric pressure set knob on the altimeter manually changes this altimeter setting on the barometric scale and results in simultaneous movement of the altitude pointers to the corresponding altitude reading.

Like all measurements, an altitude reading is meaningless if the point from which it starts is unknown. The face of the pressure altimeter supplies both values. The position of the pointers indicates the altitude in feet, and the barometric pressure appearing on the barometric scale is that of the reference plane above which the measurement is made.

Altimeter Displays

THREE-POINTER ALTIMETER. The three-pointer altimeter illustrated in figure 4-17 has three concentrically mounted pointers which are coded by length and shape. The triangular-tipped pointer indicates 10,000's of feet, the small pointer indicates 1,000's of feet, and the long pointer indicates 100's of feet and parts of hundreds. The smallest graduations on the dial are 20-foot increments between hundreds of feet. The 100-foot pointer makes one complete revolution in each 1,000 feet of altitude change; the 1,000-foot pointer makes one complete revolution in each 10,000 feet of altitude change; the 10,000 foot pointer makes one complete revolution in each 100,000 feet of altitude change. A low-altitude warning symbol (hash marks) is visible at altitudes below 16,000 feet. Newer models of this altimeter include an additional 10,000-foot reference consisting of a narrow white stripe around the inner perimeter of the instrument scale. This stripe becomes visible as the 10,000-foot pointer moves clockwise. When this feature is present, the low

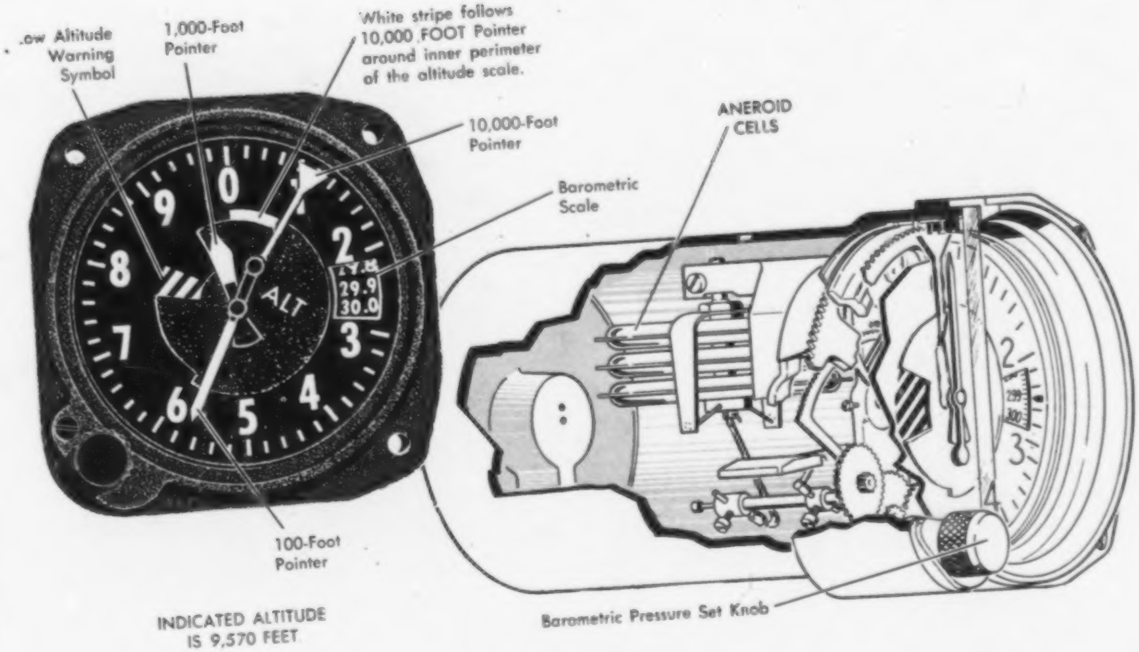

Low Altitude Warning Symbol
1,000-Foot Pointer
White stripe follows 10,000 FOOT Pointer around inner perimeter of the altitude scale.
10,000-Foot Pointer
Barometric Scale
ANEROID CELLS
100-Foot Pointer
Barometric Pressure Set Knob
INDICATED ALTITUDE IS 9,570 FEET
ALT
29.9
30.0

Figure 4-17. Three-Pointer Altimeter

altitude warning symbol is relocated to the nine o'clock position. To determine the indicated altitude, first read the 10,000-foot pointer, then the 1,000-foot pointer, and last, the 100-foot pointer.

Counter-Pointer Altimeter. The counter-pointer altimeter has a two-counter digital display unit located in the nine o'clock position of the dial. The counter indicates altitude in 1,000-foot increments from zero to 80,000 feet. See figure 4-18. A single conventional pointer indicates 100's of feet on the fixed circular scale. It makes one complete revolution per 1,000 feet of altitude change, and as it passes through the 900- to 1,000-foot area of the dial, the 1,000 foot counter is actuated. The shaft of the 1,000-foot counter in turn actuates the 10,000-foot counter at each 10,000 feet of altitude change. To determine the indicated altitude, first read the 1,000-foot counter and then add the 100-foot pointer indication.

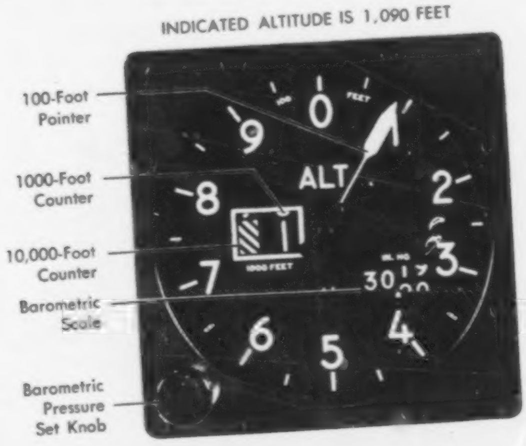

INDICATED ALTITUDE IS 1,090 FEET
100-Foot Pointer
1000-Foot Counter
10,000-Foot Counter
Barometric Scale
Barometric Pressure Set Knob
ALT
1000 FEET

Figure 4-18. Counter-Pointer Altimeter

CAUTION

It is possible to misinterpret the counter-pointer altimeter by 1,000 feet immediately before or immediately after the 1,000-foot counter moves. This error is possible because the 1,000-foot counter changes when the 100-foot pointer is between the 900- and 1000-foot position.

Counter-Drum-Pointer Altimeter. Aside from the familiar circular scale and 100-foot pointer, the counter-drum-pointer presentation differs somewhat in appearance from the present three-pointer altimeter. Starting at the left of the

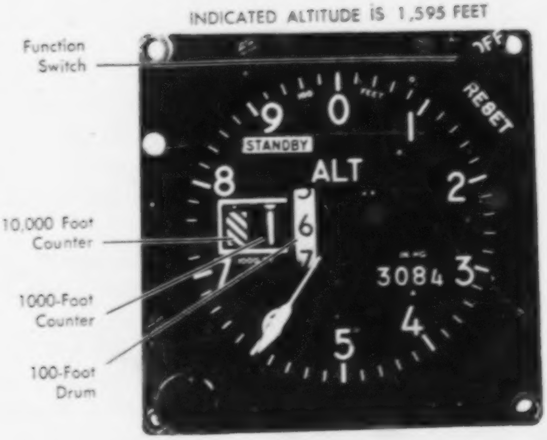


Figure 4-19. Counter-Drum-Pointer Altimeter

instrument illustrated in figure 4-19 and reading from left to right, there are two counter windows and one drum window (white). The numerals presented in the counter windows indicate 10,000's and 1,000's of feet respectively. The drum window numbers always follow the pointer number, thereby indicating 100's of feet.

Two methods may be used to read indicated pressure altitude on the counter-drum-pointer altimeter: (1) read the counter-drum window, without referring to the 100-foot pointer, as a direct digital readout of both thousands and hundreds of feet; (2) read the two counter indications, without referring to the drum, and then add the 100-foot pointer indication. The 100-foot pointer serves as a precise readout of values less than 100 feet.

The differential air pressure which is used to operate the counter-drum-pointer altimeter is processed by an altitude transducer where it is converted to electrical signals that drive the indicator. The transducer is also used to send digital signals to a transponder for purposes of automatic altitude reporting to Air Route Traffic Control Centers. A standby system is available for use should an electrical malfunction occur. In the standby system, the altimeter receives static air pressure directly from the pitot-static system. When the instrument is operating in the standby system, the word STANDBY appears on the instrument face. A switch in the upper right-hand corner of the instrument is provided to return the instrument to its normal mode of operation. This switch may also be used to manually place the instrument in the STANDBY mode.

Altimeter Errors

The pressure altimeter is subject to certain errors which fall in five general categories.

MECHANICAL ERROR. Mechanical error is caused by misalignments in gears and levers which transmit the aneroid cell expansion and contraction to the pointers of the altimeter. This error is not constant and must be checked before each flight by the setting procedure.

SCALE ERROR. Scale error is caused by irregular expansion of the aneroid cells and is recorded on a scale correction card maintained for each altimeter in the instrument maintenance shop.

INSTALLATION/POSITION ERROR. Installation position error is caused by the airflow around the static ports. This error varies with the type of aircraft, airspeed, and altitude. The magnitude and direction of this error can be determined by referring to the performance data section in the aircraft technical order.

An altimeter correction card is installed in some aircraft which combines the installation/position and scale errors. The card indicates the amount of correction required at different altitudes and airspeeds.

WARNING

Installation/position error may be considerable at high speeds and altitudes. Apply the corrections as outlined in the technical order or on the altimeter correction card.

REVERSAL ERROR. Reversal error is caused by inducing false static pressure in the static system. It normally occurs during abrupt or large pitch changes. This error appears on the altimeter as a momentary indication in the opposite direction.

HYSTERESIS ERROR. Hysteresis error is a lag in altitude indication caused by the elastic properties of the material within the altimeter. This occurs after an aircraft has maintained a constant altitude for an extended period of time and then makes a large, rapid altitude change. After a rapid descent, altimeter indications are higher than actual. This error is negligible during climbs and descents at slow rates or after maintaining a new altitude for a short period of time.

Setting the Altimeter

The barometric scale is used to set a reference plane into the altimeter. Rotating the barometric pressure set knob increases or decreases the scale reading and the indicated altitude. Each .01 change on the barometric scale is equal to 10 feet of altitude.

The majority of altimeters have mechanical stops at or just beyond the barometric scale limits (28.10 to 31.00).

NOTE: Those altimeters not equipped with mechanical stops near the barometric scale limits can be set with a 10,000-foot error. Therefore, when setting the altimeter, insure that the 10,000-foot pointer is reading correctly.

The altimeter must be checked for accuracy before every flight. To check and set the altimeter:

1. Set the current altimeter setting on the barometric scale. Tap altimeter gently.

2. Check altimeter at a known elevation and note the error in feet.

3. If the error exceeds 75 feet, do not use the altimeter for IFR flights.

Nonstandard Atmosphere Effects

The altimeter setting is a correction for nonstandard surface pressure only. Atmospheric pressure is measured at each station and the value obtained is corrected to sea level according to the surveyed field elevation. Thus, the altimeter setting is computed sea level pressure and should be considered valid only in close proximity to the station and the surface. It does not reflect nonstandard temperature nor distortion of atmospheric pressure at higher altitudes.

NOTE: Except for terrain clearance, the navigator should disregard nonstandard atmospheric effects for Air Traffic Control purposes. All altimeters within proximity of one another react to these effects in the same way, thus normal vertical separation among aircraft is provided. A complete discussion of these effects is found in AFM 105-5.

Types of Altitude

INDICATED ALTITUDE. The term, indicated altitude, means simply the value of altitude that is displayed on the pressure altimeter.

CALIBRATED ALTITUDE. Calibrated altitude is indicated altitude corrected for installation/position error.

PRESSURE ALTITUDE. The height above the standard datum plane (29.92" Hg and +15°C) is pressure altitude (refer to figure 4-16).

DENSITY ALTITUDE. Ordinarily, the pressure lapse rate above the ground is not standard; it varies with temperature. Therefore, basic pressure altitude must be corrected for temperature variation to find density altitude. Air expands with increase in temperature. Consequently, warm air is less dense than cold air. As a result, the pressure lapse rate is less in a column of warm air than in cold air. That is, pressure decreases more rapidly with height in cold air than in warm air. Consequently, an altimeter tends to read too high in cold air and too low in warm air as shown in figure 4-20. Density altitude is of interest primarily in the control of engine performance and is of direct concern to the navigator in connection with cruise control.

TRUE ALTITUDE. True altitude is the actual vertical distance above mean sea level, measured in feet. It can be determined by two methods: (1) Set the local altimeter setting on the barometric scale of the pressure altimeter to obtain the indicated true altitude. The indicated true altitude can then be resolved to true altitude by use of the DR computer (refer to figure 4-16). (2) Measure altitude over water with an absolute altimeter.

ABSOLUTE ALTITUDE. The height above the terrain is called absolute altitude. It is computed by subtracting terrain elevation from true altitude, or it can be read directly from an absolute altimeter.

Computer Altitude Solutions

The two altitudes most commonly accomplished on the computer are true altitude and density altitude. Nearly all DR computers have a window by which density altitude can be determined; however, be certain that the window is labeled DENSITY ALTITUDE.

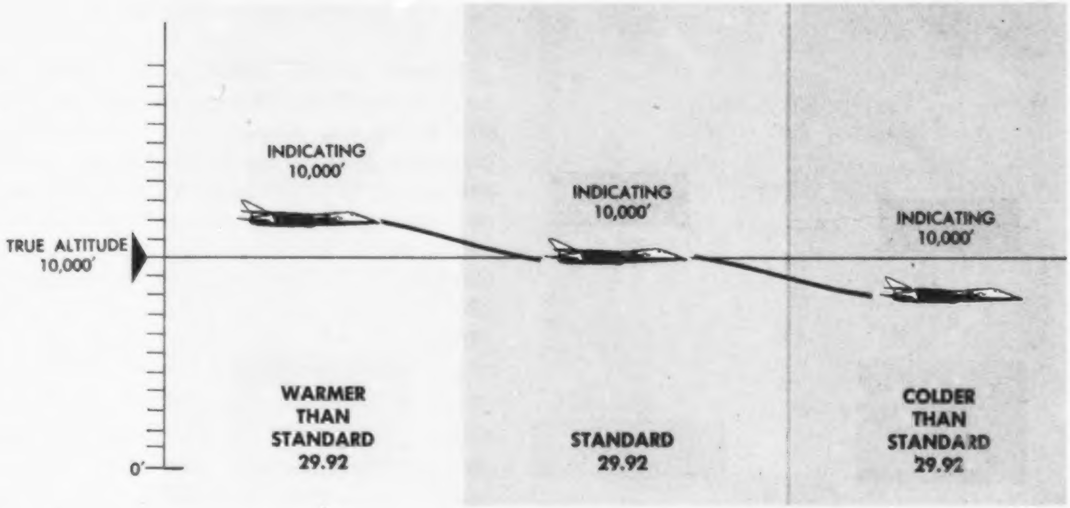

INDICATING
10,000′
INDICATING
10,000′
INDICATING
10,000′
TRUE ALTITUDE
10,000′
0′
WARMER
THAN
STANDARD
29.92
STANDARD
29.92
COLDER
THAN
STANDARD
29.92

Figure 4-20. True Altitude Decreases Going Into Cold Air

TRUE ALTITUDE DETERMINATION. In the space marked FOR ALTITUDE COMPUTATIONS are two scales: (1) a centigrade scale in the window and (2) a pressure altitude scale on the upper disk. When a pressure altitude is placed opposite the temperature at that height, all values on the outer (miles) scale are equal to the corresponding values on the inner (minutes) scale increased or decreased by two percent for each 5.5°C that the actual temperature differs from the standard temperature at that pressure altitude, as set in the window.

Although the pressure altitude is set in the window, the indicated true altitude is used on the inner (minutes) scale for finding the true altitude, corrected for difference in temperature lapse rate.

Example:

Given: Pressure altitude 8,500 feet
Indicated true altitude 8,000 feet
Air Temperature (°C)—15

To Find: True altitude

Procedure: Place PA (8,500 feet) opposite the temperature (—16) on the FOR ALTITUDE COMPUTATIONS scale. Opposite the indicated true altitude (8,000 feet) on the inner scale, read the true altitude (7,600 feet) on the outer scale. The solution is illustrated in figure 4-21.

DENSITY ALTITUDE DETERMINATION. Density altitude determination on the computer is accomplished by using the window just above FOR AIRSPEED AND DENSITY ALTITUDE COMPUTATIONS and the small window just above that marked DENSITY ALTITUDE.

Example:

Given: Pressure altitude 9,000 feet
Air temperature (°C) +10

To Find: Density altitude

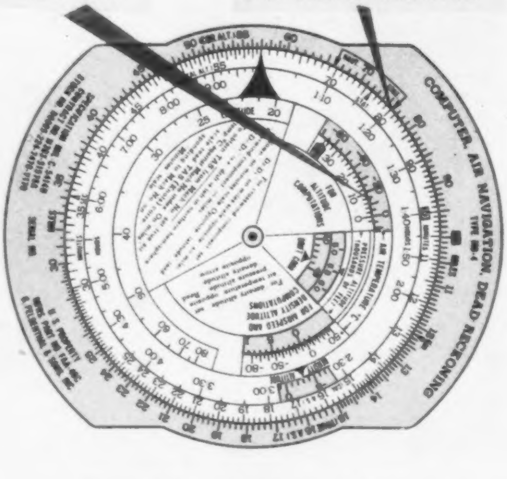
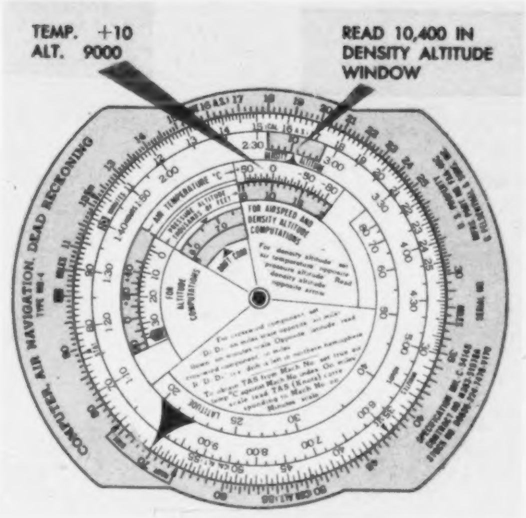

TEMP. —16
ALT. 8500
READ 7600 ON MILES SCALE
OVER 8000 ON MIN. SCALE
COMPUTER, AIR NAVIGATION, DEAD RECKONING

Figure 4-21. Finding True Altitude


TEMP. +10
ALT. 9000

READ 10,400 IN DENSITY ALTITUDE WINDOW

COMPUTER, AIR NAVIGATION, DEAD RECKONING
FOR AIRSPEED AND DENSITY ALTITUDE COMPUTATIONS
AIR TEMPERATURE °C
PRESSURE ALTITUDE THOUSANDS OF FEET

Figure 4-22. Finding Density Altitude

Procedure: Place pressure altitude (9,000 feet) opposite air temperature (+10) in window marked FOR AIRSPEED AND DENSITY ALTITUDE window, read density altitude (10,400 feet). The solution is illustrated in figure 4-22.

ABSOLUTE ALTIMETER

Accurate absolute altitude is an important requisite for navigation, photography, and bombing as well as for safe piloting. It is particularly important in pressure pattern navigation. Absolute altitude may be computed from the pressure altimeter readings if the position of the aircraft is known, but the results are often inaccurate. Under changing atmospheric conditions, corrections applied to pressure altimeter readings to obtain true altitudes are only approximate. In addition, any error made in determining the terrain elevations results in a corresponding error in the absolute altitude. Such an error in absolute altitude makes groundspeeds by timing inaccurate and precludes reasonable accuracy of soundings for pressure pattern navigation.

Electronic Altimeter Set (High Level)

A typical high level radar altimeter is designed to indicate absolute altitude of the aircraft up to 70,000 feet above the terrain, land or water. Altitude indicated is presented on the calibrated face of a cathode ray tube. This altimeter does not warn of approaching obstructions such as moun-

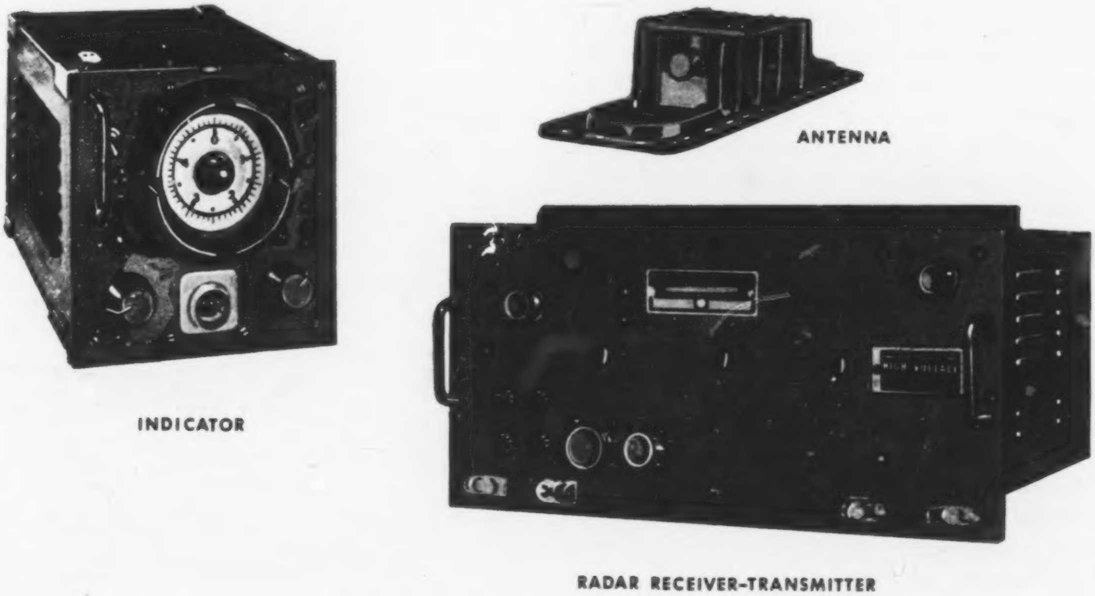

INDICATOR
ANTENNA
RADAR RECEIVER-TRANSMITTER

Figure 4-23. Absolute Altimeter System Components

tains because it measures altitude only to a point directly below the aircraft.

Components and Operating Principle. A typical set consists of the radar receiver-transmitter, height indicator, and antenna as shown in figure 4-23. The transmitter section of the receiver-transmitter unit develops recurring pulses of radio frequency (RF) energy which are delivered to the transmitter antenna located either flush mounted or on the underside of the aircraft. The transmitter antenna radiates the pulsed energy downward to reflect off the earth and return to the receiver antenna on the aircraft. The time consumed between transmission and reception of the RF pulse is determined only by the absolute altitude of the aircraft above the terrain since the radio wave velocity is constant. The receiver antenna delivers the returned pulse to the receiver section of the receiver-transmitter unit where it is amplified and detected for presentation on the indicator unit. On the indicator CRT a circular trace and a zero reference pulse are started coincidentially with emission of the transmitted pulse. The returned pulse, which arrives later, is displayed at a point on the circular trace determined by the aircraft absolute altitude. Calibration marks on the CRT face provide an altitude-reading scale.

Reading Altitude. The operating controls and reading scale of a typical set are located on the front panel of the indicator, shown in figure 4-24. To put such a set into operation, turn the REC GAIN knob clockwise and allow a few minutes for warmup.

The reading scale is a circular trace. One complete revolution represents either 5000 feet or 50,000 feet, depending on the position of the TIMES ONE (X-1), TIMES TEN (X-10), switch.

When the set is operating, two lobes appear on the trace. One is the zero reference lobe which can be adjusted to coincide with zero on the scale. The other lobe is the reflected or altitude lobe which moves around the scale according to the absolute altitude of the aircraft.

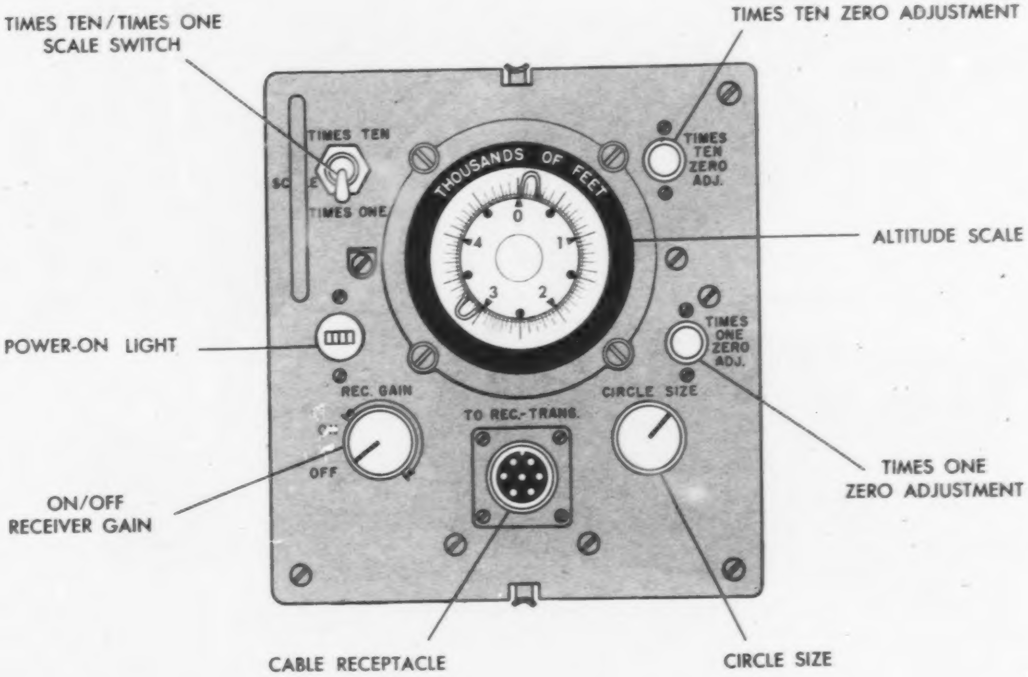

TIMES TEN / TIMES ONE SCALE SWITCH
TIMES TEN ZERO ADJUSTMENT
TIMES TEN
SCALE
TIMES ONE
THOUSANDS OF FEET
0
1
2
3
4
TIMES TEN ZERO ADJ.
ALTITUDE SCALE
POWER-ON LIGHT
TIMES ONE ZERO ADJ.
REC. GAIN
OFF
TO REC.-TRANS.
CIRCLE SIZE
TIMES ONE ZERO ADJUSTMENT
ON/OFF RECEIVER GAIN
CABLE RECEPTACLE
CIRCLE SIZE

Figure 4-24. Absolute Altimeter (Indicator)

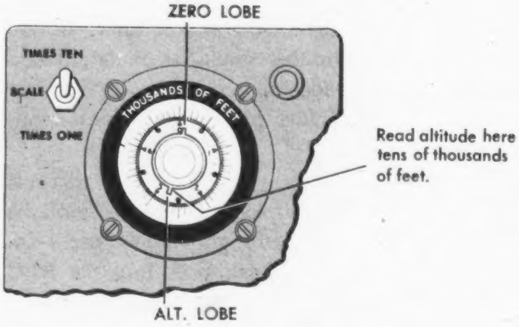

ZERO LOBE
TIMES TEN
SCALE
TIMES ONE
THOUSANDS OF FEET
Read altitude here tens of thousands of feet.
ALT. LOBE

Figure 4-25. Reading Indicator, Times Ten Scale

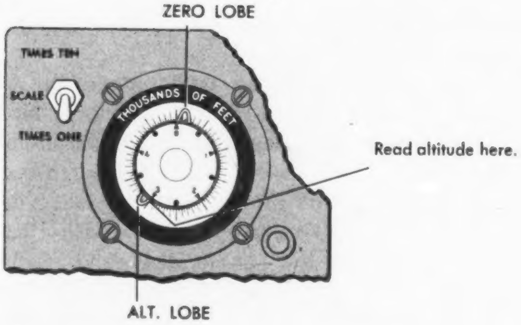

ZERO LOBE
TIMES TEN
SCALE
TIMES ONE
THOUSANDS OF FEET
Read altitude here.
ALT. LOBE

Figure 4-26. Reading Indicator, Times One Scale

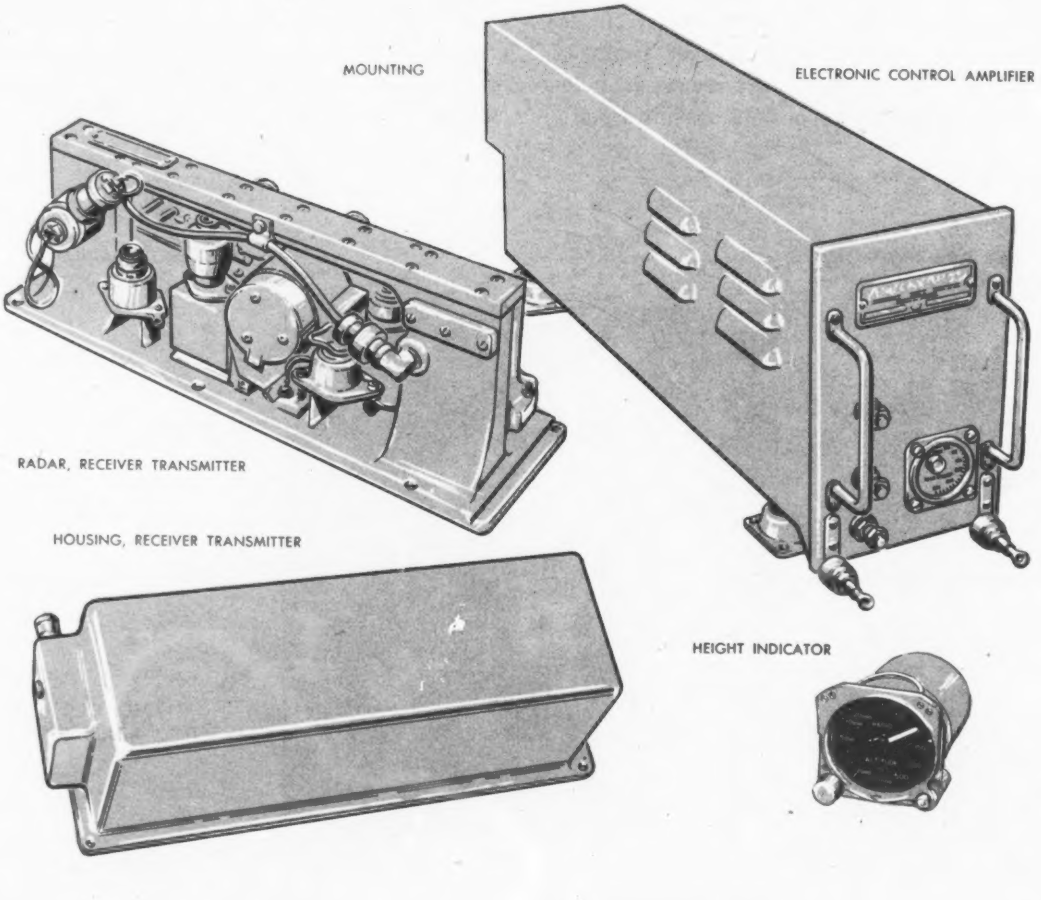

MOUNTING
ELECTRONIC CONTROL AMPLIFIER
RADAR, RECEIVER TRANSMITTER
HOUSING, RECEIVER TRANSMITTER
HEIGHT INDICATOR

Figure 4-27. Radar Altimeter Set

Reading this type of altimeter is illustrated. In the X-10 position (figure 4-25), the indicator shows the altitude to be between 25,000 and 30,000 feet. Read the 5,000-foot marker next below the position of the lobe (25,000 feet). Next place the scale switch in the X-1 position (figure 4-26) and take the exact altitude indicated (3,000 feet). The sum of the two altitude readings (25,000 feet plus 3,000 feet) is equal to the exact radar height of the aircraft (28,000 feet).

Radar Altimeter (Low Level)

This type altimeter provides a dial indication of the altitude of the aircraft above the terrain. It is designed to eliminate the necessity of adding antennas or any other equipment external to the surface of the aircraft. This equipment may also be used in conjunction with automatic pilot or other devices requiring altitude limit data.

The components of a typical system include the receiver-transmitter, the height indicator, and the electronic control amplifier (figure 4-27). The height indicator contains the only operating control on the equipment. This instrument gives altitude readings of the aircraft up to 10,000 feet over land and up to 20,000 feet over water. The scale is logarithmic and is graduated in 10's of feet for the first 200 feet. From 200 feet to 20,000 feet, the graduations are gradually compressed. A limit indicator system is included to provide an indication of flight below a preset altitude.

To operate the equipment, turn the ON-LIMIT control to ON. After warmup, the terrain clearance of the aircraft within the range of 0-20,000 is read directly from the single printer on the indicator face. Notice the small triangular mark on the indicator in figure 4-28. This pointer can be preset to any desired altitude by the ON-LIMIT control and is used as a reference for flying at fixed altitudes. The altitude can be maintained by observing the position of the pointer with respect to the small triangular marker instead of the actual altitude scale. In addition, a red light on the front of the indicator lights up when the aircraft is at or below the preset altitude. To turn off the equipment, it is only necessary to turn off the ON-LIMIT control on the indicator.

TEMPERATURE

Determination of correct temperature is necessary for accurate computation of airspeed and altitude. Temperature, airspeed, and altitude are all closely interrelated, and the practicing navigator must be familiar with each in order to work effectively and accurately.

Temperature Gages

The temperature gage most commonly used in the Air Force employs a bimetallic element. The instrument, illustrated in figure 4-29, is a single unit consisting of a stainless steel stem which projects into the air stream and a head which contains the pointer and scale. The sensitive ele-

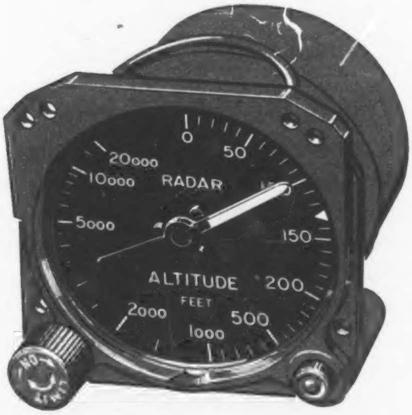


Figure 4-28. Radar Height Indicator

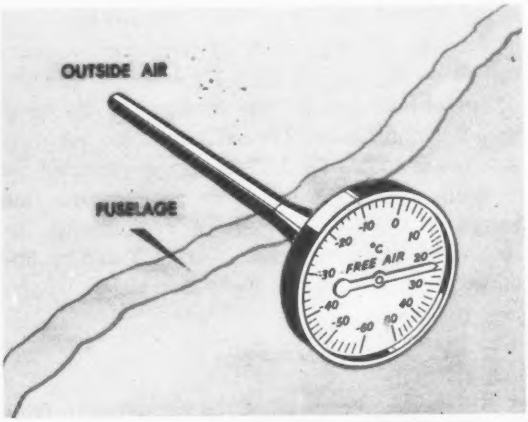


Figure 4-29. Free Air Temperature Gage

ment in the end of the stem—projected outside the aircraft—is covered by a radiation shield of brightly polished metal to cut down the amount of heat that the element might absorb by direct radiation from the sun.

The bimetallic element (called the sensitive element) is so named because it consists of two strips of different metal alloys welded together. When the element is heated, one alloy expands more rapidly than the other causing the element, which is shaped like a coil spring, to turn. This, in turn, causes the indicator needle to move on the pointer dial. Temperature between −60°C and +50°C can be measured on this type of thermometer.

Temperature Scales

In the United States, temperature is usually expressed in terms of the Fahrenheit scale (°F). In aviation, temperature is customarily measured on the centigrade, or Celsius, (°C) scale.

Although aircraft thermometers are usually calibrated in °C, it is sometimes necessary to interconvert Fahrenheit and centigrade temperatures. The following formulas may be used:

$$°F = (1.8 \times °C) + 32°$$

$$°C = \frac{°F - 32°}{1.8}$$

Temperature error is the total effect of scale error and heat of compression error. *Scale error* is simply an erroneous reading of the pointer under standard conditions. It is difficult for a crew member to evaluate this error without sensitive testing equipment. With this in mind, the reading of the indicator is considered correct and is called indicated air temperature (IAT).

The second error, *heat of compression error,* causes the instrument to read too warm. Heating occurs at high speeds from friction and the compression of air on the forward edge of the temperature probe. Thus the IAT is always corrected by a minus correction factor to produce true air temperature (TAT). Heat of compression increases with true airspeed. The TAT can be obtained from the aircraft flight manual.

AIRSPEED

Airspeed is the speed of the aircraft with relation to the air mass surrounding that aircraft.

Pitot-Static System

Accurate airspeed measurement is obtained by means of a pitot-static system. The system consists of: (1) a tube mounted parallel to the longitudinal axis of the aircraft in an area that is free of turbulent air generated by the aircraft, and (2) a static source that provides still, or undisturbed, air pressure.

Ram and static pressures may be taken from a single pitot-static tube or from completely separate sources. A pitot-static tube usually has a baffle plate, as shown in figure 4-30, to reduce turbulence and to prevent rain, ice, and dirt from entering the tube. There may be one or more drain holes in the bottom of the tube to dispose of condensed moisture. A built-in electrical heating element, controlled by a switch inside the aircraft, prevents the formation of ice in the tube.

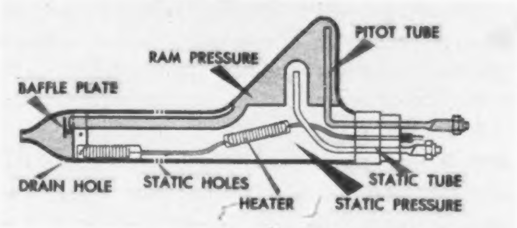


Figure 4-30. Structure of the Pitot Tube

Reasonable care should be taken with the pitot-static system to insure continuous, reliable service. The drain holes should be checked periodically to insure they are not clogged. At the completion of each flight, a cover is placed over the intake end of the tube to prevent dirt and moisture from collecting in the tube.

Principles of Operation of Airspeed Indicator

The heart of the airspeed indicator is a diaphragm which is sensitive to pressure changes. Figure 4-31 shows it located inside the indicator case and connected to the ram air source in the pitot tube. The indicator case is sealed airtight and connected to the static pressure source. The differential pressure created by the relative effects of the impact and static pressures on the diaphragm causes it to expand or contract. As the speed of the aircraft increases, the impact pressure increases, causing the diaphragm to expand. Through mechanical linkage, the expansion is displayed as an increase in airspeed. This principle is used in the indicated airspeed meter, the true airspeed meter, and the Machmeter.

Airspeed Definitions

There are many reasons for the difference between indicated airspeed and true airspeed. Some of these reasons are the error in the mechanical makeup of the instrument, the error caused by incorrect installation, and the fact that density and pressure of the atmosphere vary from standard conditions.

INDICATED AIRSPEED (IAS). Indicated airspeed is the uncorrected reading taken from the face of the indicator. It is the airspeed that the instrument shows on the dial. It can be read in miles per hour or in knots, depending upon the scale of the dial.

BASIC AIRSPEED (BAS). Basic airspeed is the indicated airspeed corrected for instrument error. Each airspeed indicator has its own characteristics which cause it to differ from any other airspeed indicator. These differences may be caused by slightly different hairspring tensions, flexibility of the diaphragm, accuracy of the scale markings, or even the effect of temperature on the different metals in the indicator mechanism. The effect of temperature introduces an instrument error due to the variance in the coefficient of expansion of the different metals comprising the working mechanism. This error can be removed by the installation of a bimetallic compensator within the mechanical linkage. This bimetallic compensator is installed and properly set at the factory, thereby eliminating the temperature error within the instrument. The accuracy of the airspeed indicator is also affected by the length and curvature of the pressure line from the pitot tube. These installation errors must be corrected mathematically. Installation, scale, and instrument errors are all combined under one title called instrument error. Instrument error is factory determined to be within specified tolerances for various airspeeds. It is considered negligible or is accounted for in TO tables and graphs.

CALIBRATED AIRSPEED (CAS). Calibrated airspeed is basic airspeed corrected for pitot-static error and/or attitude of the aircraft. The pitot-static system of a moving aircraft will have some error. Minor errors will be found in the pitot section of the system. The major difficulty is encountered in the static pressure section. As the flight attitude of the aircraft changes, the pressure

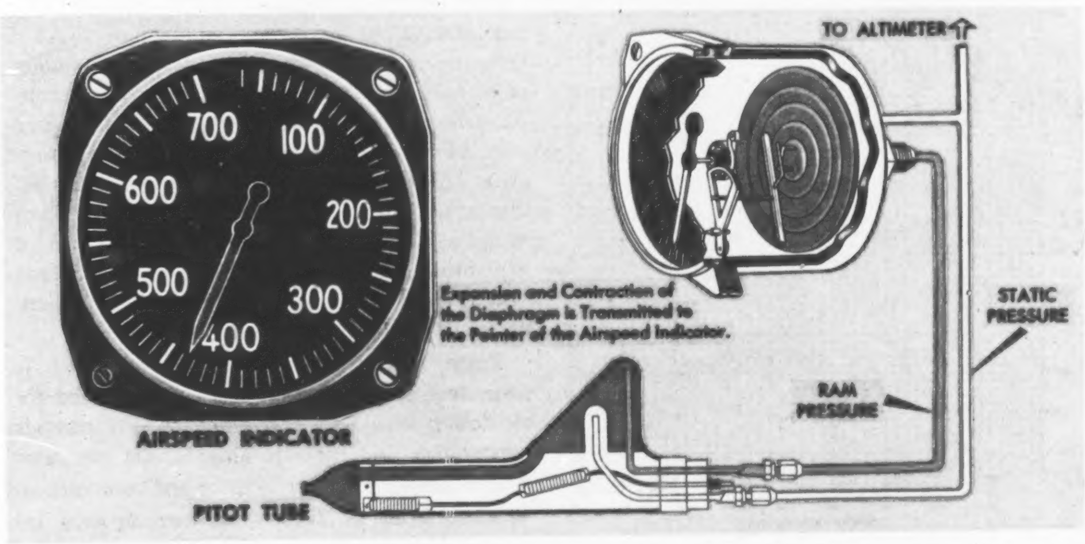

TO ALTIMETER
700
100
600
200
500
300
400
Expansion and Contraction of the Diaphragm is Transmitted to the Pointer of the Airspeed Indicator.
STATIC PRESSURE
RAM PRESSURE
AIRSPEED INDICATOR
PITOT TUBE

Figure 4-31. Operating Principle of the Airspeed Indicator

at the static inlets changes. This is caused by the airstream striking the inlet at an angle. Different types and locations of installations cause different errors. It is immaterial whether the static source is located in the pitot-static head or at some flush mounting on the aircraft. This error will be essentially the same for all aircraft of the same model, and a correction can be computed by referring to tables found in the appendix of the appropriate flight manual (see figure 4-32).

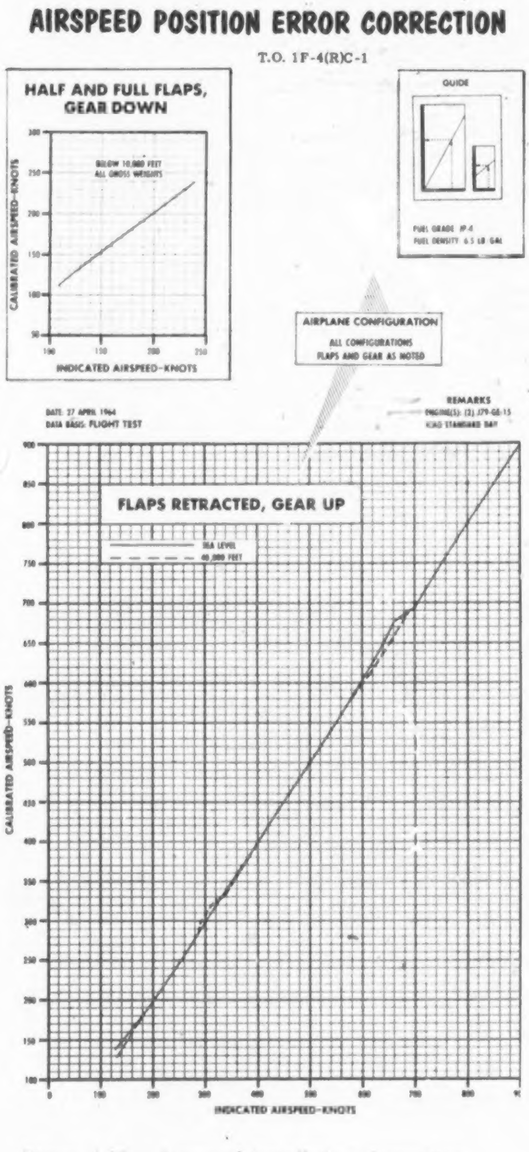


Figure 4-32. Airspeed Installation Correction

EQUIVALENT AIRSPEED (EAS). Equivalent airspeed is calibrated airspeed corrected for compressibility. Compressibility error has come into prominence with the advent of high speed aircraft. It becomes noticeable when the airspeed is great enough to create an impact pressure which causes the air molecules to be compressed within the impact chamber of the pitot tube. The amount of compression is directly proportionate to the impact pressure. As the air is compressed, it causes the dynamic pressure to be greater than it should be. Therefore, the correction is a negative value. The correction for compressibility error can be determined by referring to the performance data section of the aircraft flight manual or by using the "F" correction factor on the DR computer.

DENSITY AIRSPEED (DAS). Density airspeed is calibrated airspeed corrected for pressure altitude and true air temperature. Pitot pressure varies not only with airspeed but also with air density. As the density of the atmosphere decreases with height, pitot pressure for a given airspeed must also decrease with height. Thus, an airspeed indicator operating in a less dense medium than that for which it was calibrated will indicate an airspeed lower than true speed. The higher the aircraft flies, the greater the discrepancy. The necessary correction can be found on the DR computer. Using the window on the computer above the area marked FOR AIRSPEED DENSITY ALTITUDE COMPUTATIONS, set the pressure altitude against the True Air Temperature (TAT). Opposite the calibrated airspeed on the minutes scale, read the density airspeed on the miles scale. At lower airspeeds and altitudes, density airspeed may be taken as true airspeed with negligible error. However, at high speeds and altitudes, this is no longer true and compressibility error must be considered. (Compressibility error is explained in the equivalent airspeed section.) When density altitude is multiplied by the compressibility factor, the result is true airspeed.

TRUE AIRSPEED (TAS). True airspeed is equivalent airspeed which has been corrected for air density error. By correcting EAS for true air temperature and pressure altitude, the navigator compensates for air density error and computes an accurate value of TAS. The true airspeed increases with altitude when the indicated airspeed remains constant. When the airspeed remains

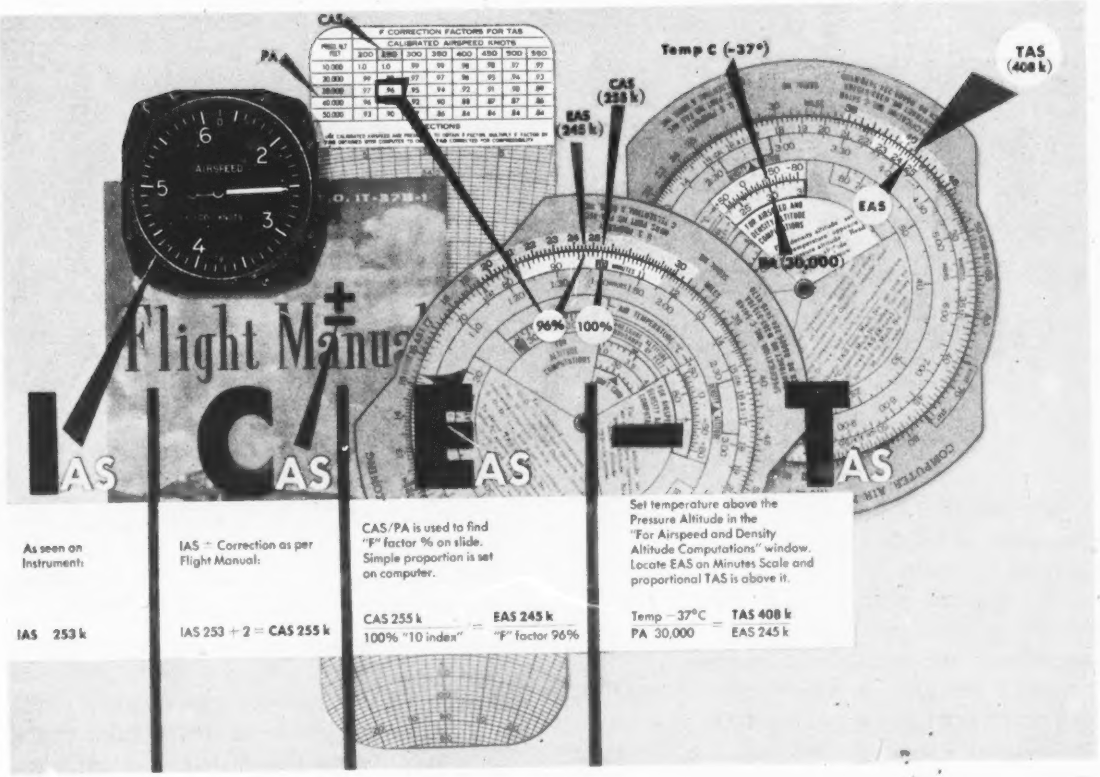

CAS
PA
Temp C (-37°)
TAS (408 k)
CAS (255 k)
EAS (245 k)
EAS
PA 30,000
96%
100%
Flight Manual
±
IAS
CAS
EAS
TAS
As seen on Instrument:
IAS 253 k
IAS ± Correction as per Flight Manual:
IAS 253 + 2 = CAS 255 k
CAS/PA is used to find "F" factor % on slide. Simple proportion is set on computer.
CAS 255 k / 100% "10 index" = EAS 245 k / "F" factor 96%
Set temperature above the Pressure Altitude in the "For Airspeed and Density Altitude Computations" window. Locate EAS on Minutes Scale and proportional TAS is above it.
Temp −37°C / PA 30,000 = TAS 408 k / EAS 245 k

Figure 4-33. ICE-T Method

constant, the indicated airspeed decreases with altitude. Calibrated and equivalent airspeeds can be determined by referring to the performance data section of the aircraft flight manual.

Computing True Airspeed

ICE-T METHOD. To compute true airspeed (TAS) using the ICE-T method on the DR computer, solve for each type of airspeed in the order of I, C, E, and T; that is, change indicated airspeed to calibrated, change calibrated to equivalent, and change equivalent to true. This process is illustrated by the following sample problem. (Refer to definitions as necessary.)

Given: Pressure Altitude (PA): 30,000′
Temperature: −37°C
Indicated Airspeed (IAS): 253 knots
Flight Manual Correction
Factor: +2 knots

Find: Calibrated Airspeed (CAS)
Equivalent Airspeed (EAS)
True Airspeed (TAS)

Answer: CAS is determined by algebraically adding to IAS the correction factor taken from the chart in your flight manual. (This correction is insignificant at low speeds but can be higher than 10 knots near Mach 1.)

To correct CAS to EAS, use the chart on the slide of the computer entitled F CORRECTION FACTORS FOR TAS. See figure 4-33. Enter the chart with CAS and PA. The F factor is .96. This means we multiply CAS by .96 or take 96% of 255 knots. To do this, place 255 knots on the inner scale under the "10" index on the outer scale. Locate 96 on the outer scale and read EAS on the inner scale: 245 knots.

Now we need to correct EAS for temperature and altitude to get TAS. As shown in figure 4-33, in the window marked FOR AIRSPEED AND DENSITY ALTITUDE COMPUTATIONS place temperature over PA. Locate the EAS of 245 knots on the inner scale and read TAS on the outer scale. The TAS is 408 knots.

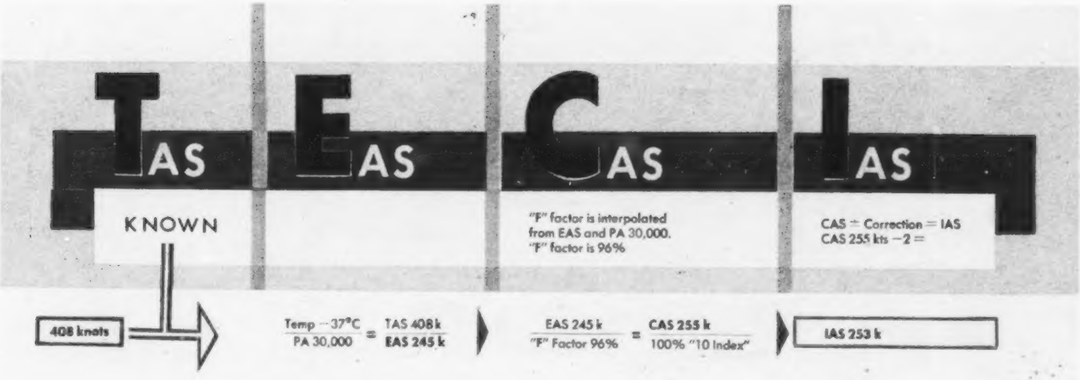

TAS
EAS
CAS
IAS
KNOWN
"F" factor is interpolated from EAS and PA 30,000.
"F" factor is 96%
CAS ± Correction = IAS
CAS 255 kts −2 =
408 knots
Temp −37°C / PA 30,000 = TAS 408 k / EAS 245 k
EAS 245 k / "F" Factor 96% = CAS 255 k / 100% "10 Index"
IAS 253 k

Figure 4-34. ICE-T Method in Reverse

ALTERNATE TAS METHOD. There is an alternate method of finding TAS when given CAS. The instructions for the alternate solution are printed on the computer directly below the F factor table. Mathematically, your answer should be the same regardless of the procedure you use, but the ICE-T method is used most often because the computation can be worked backwards from TAS. If you wish to maintain a constant TAS, you can determine what CAS or IAS to fly, by working the ICE-T method in reverse as illustrated in figure 4-34.

Machmeters

Machmeters indicate the ratio of aircraft speed to the speed of sound at any particular altitude and temperature during flight. It is often necessary to convert TAS to a Mach number or vice versa. Instruction are clearly written on the computer in the center portion of the circular slide rule.

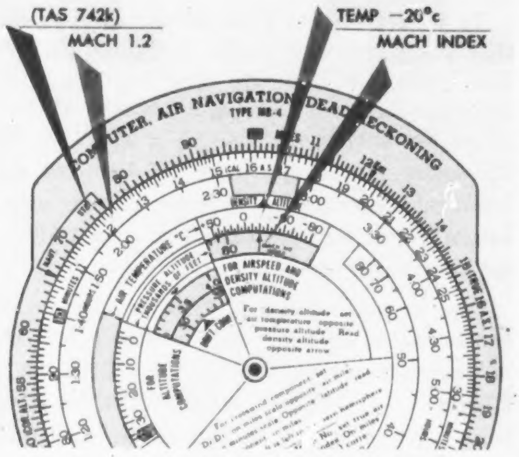

(TAS 742k)
MACH 1.2
TEMP −20°c
MACH INDEX
COMPUTER, AIR NAVIGATION DEAD RECKONING
TYPE MB-4
FOR AIRSPEED AND DENSITY ALTITUDE COMPUTATIONS
FOR ALTITUDE COMPUTATIONS

Figure 4-35. Finding TAS from Mach Number

Locate the window marked FOR AIRSPEED AND DENSITY ALTITUDE COMPUTATIONS and rotate the disc until the window points to the top of the computer (toward the 10 index on the outer scale). Within the window is an arrow entitled MACH NO. INDEX. See figure 4-35. To obtain TAS from a given Mach number, set air temperature over the MACH NO. INDEX, and opposite the Mach number on the MINUTES scale, read the TAS on the outer scale.

Example: If you are planning to maintain Mach 1.2 on a cross-country flight, place the air temperature at flight altitude over the MACH NO. INDEX. Read the TAS on the outer scale opposite 1.2 on the inner scale. If the temperature is −20°C, the TAS will be 742 knots.

AIRSPEED INDICATORS

True Airspeed Indicator

Most true airspeed indicators display true airspeed by a single pointer on a fixed circular scale as illustrated in figure 4-36. They employ an aneroid cell, a differential pressure diaphragm, and a temperature diaphragm to measure impact pressure, barometric pressure, and free air temperatures. The combined actions of the diaphragms mechanically compensate for air density error to provide an indication of true airspeed.

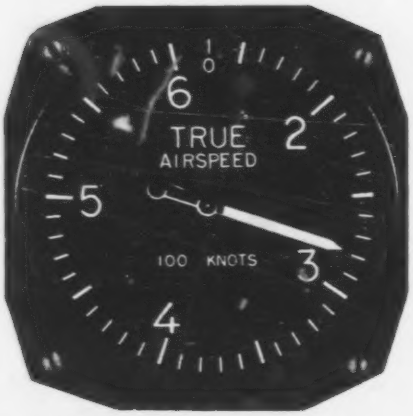

TRUE
AIRSPEED
100 KNOTS
0
2
3
4
5
6

Figure 4-36. True Airspeed Indicator

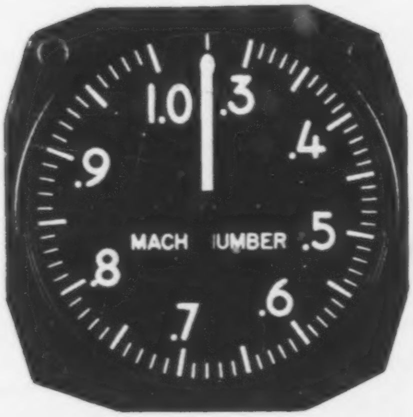

MACH UMBER
1.0
.3
.4
.5
.6
.7
.8
.9

Figure 4-38. Mach Indicator

Maximum Allowable Airspeed Indicator

This indicator, figure 4-37, displays indicated airspeed in 100's of knots by an indicated airspeed pointer on a fixed circular scale. It displays values less than 100 knots on a rotating scale in a readout window. A maximum allowable indicated airspeed pointer continuously indicates the maximum allowable indicated airspeed for the particular aircraft. Its indications are governed by an aneroid cell which expands as altitude increases, causing the maximum allowable indicated airspeed pointer indications to decrease. The maximum allowable Mach marker is set to the maximum allowable indicated Mach number for the aircraft.

Mach Indicator

The Mach indicator, shown in figure 4-38, displays Mach number which is the ratio between the true airspeed of the aircraft and the speed of sound at flight altitude. In computing a true airspeed from indicated airspeed, air density must be taken into account. This requires that a correction for temperature and altitude be made on a DR computer. With a Mach number, these corrections are unnecessary because the existing temperature at flight level determines the speed of sound at flight level. The Mach number is determined by the speed of sound, which in turn is determined by air density; thus, Mach is always a valid index to the speed of the aircraft.

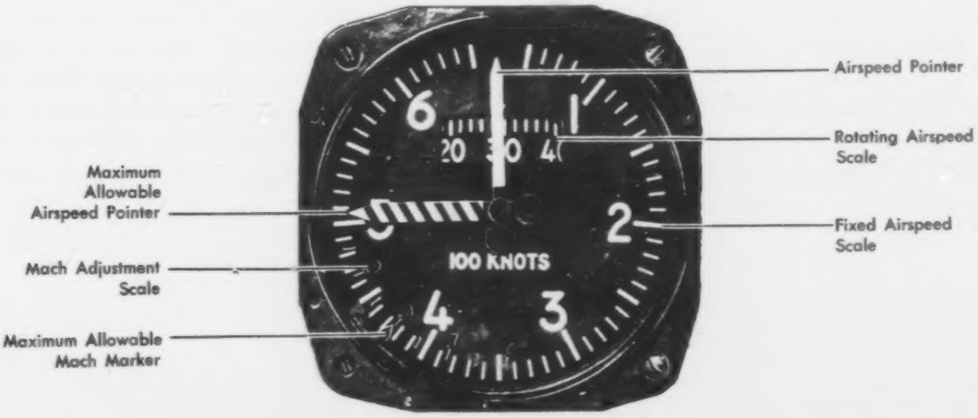

Airspeed Pointer
Rotating Airspeed Scale
Fixed Airspeed Scale
Maximum Allowable Airspeed Pointer
Mach Adjustment Scale
Maximum Allowable Mach Marker
100 KNOTS
20 30 40

Figure 4-37. Maximum Allowable Airspeed Indicator

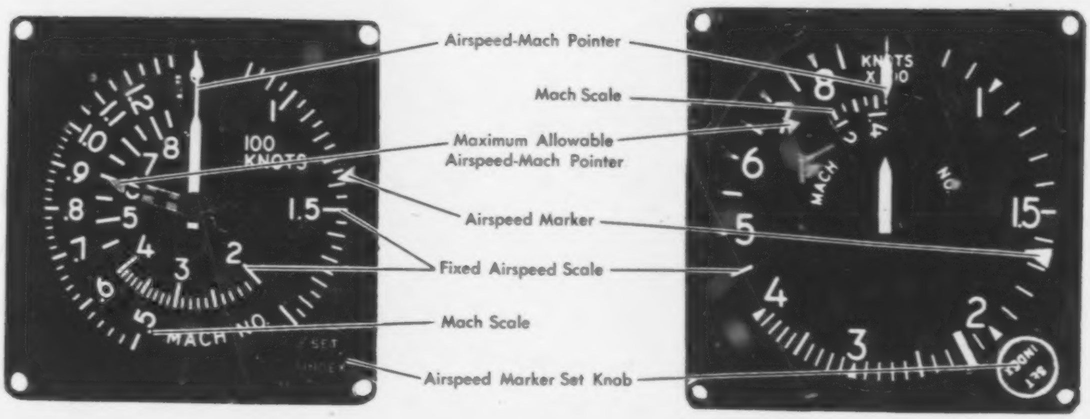


Figure 4-39. Combined Airspeed-Mach Indicators

Combined Airspeed-Mach Indicator

The combined airspeed-Mach indicator, shown in figure 4-39 is usually found in high-performance aircraft or where instrument panel space is limited. It simultaneously displays indicated airspeed, indicated Mach number, and maximum allowable airspeed. It contains a differential pressure diaphragm and two aneroid cells. The diaphragm drives the airspeed-Mach pointer. One aneroid cell rotates the Mach scale, permitting indicated airspeed and Mach number to be read simultaneously. The second aneroid cell drives the maximum allowable airspeed pointer. This pointer is preset to the aircraft's maximum indicated airspeed. Unlike the maximum indicated airspeed and unlike the maximum allowable airspeed, Mach number increases with altitude. An airspeed marker set knob positions a movable airspeed marker. This marker serves as a memory reference for desired airspeeds.

Summary of Types of Airspeed

INDICATED AIRSPEED (IAS) is the uncorrected reading taken directly from the indicator.

BASIC AIRSPEED (BAS) is the IAS corrected for instrument error.

CALIBRATED AIRSPEED (CAS) is the BAS corrected for pitot-static system error, and error induced by the attitude of the aircraft.

EQUIVALENT AIRSPEED (EAS) is CAS corrected for compressibility error.

DENSITY AIRSPEED (DAS) is the CAS corrected for pressure and temperature.

TRUE AIRSPEED (TAS) is EAS corrected for air density error (pressure and temperature). Other TAS relationships are as follows:

TAS = Density airspeed corrected for compressibility

TAS = True Mach corrected for true air temperature

INDICATED MACH NUMBER (IMN) is the Mach number displayed on the Mach indicator.

TRUE MACH NUMBER (TMN) is indicated Mach corrected for installation/position error.

Calibrated and equivalent airspeed and true Mach can be determined by referring to the performance data section of the aircraft flight manual.

CHAPTER 5

Dead Reckoning

The navigator builds his knowledge upon certain fundamentals. In navigation these basic ideas or methods are called *dead reckoning (DR) procedures.* Correct use of the plotter, dividers, computer, and charts to solve the three basic problems of navigation (position of the aircraft, direction to destination, and time of arrival) all make up dead reckoning procedures.

It is possible, using only basic instruments such as the pressure altimeter, compass, airspeed meter, and driftmeter, to navigate directly to any place in the world. But this would take conditions approaching the ideal such as good weather and perfect instruments. Therefore aids to dead reckoning or DR such as celestial, radar, loran, map reading, etc., have been developed to correct inadequacies of basic navigation. These aids are primarily known as fixing aids, and they provide information from which the fundamental skills of DR can be used to compute winds, groundspeeds, and alterations to the path of the aircraft in order to complete an assigned mission.

Thus, proficiency in DR procedures is indispensable if full use is to be made of the aids to navigation.

PLOTTING

A navigator must learn proper chart work before he can direct an aircraft from one point to another. The structure and properties of maps and charts have been covered. Now, the next step is plotting positions and directions or lines on a chart. Chart work should be an accurate and graphic picture of the progress of the aircraft from departure to destination and, with the log, should serve as a complete record of the flight. Thus it also follows that the navigator must be familiar with and use accepted standard symbols and labels on his chart as shown in figure 5-1.

Explanation of Terms

Several terms have been mentioned in earlier portions of this manual. Precise definitions of these terms must now be understood before the mechanics of chart work are learned.

AIR VECTOR (TH-TAS) **True heading and airspeed**	——>——	**DR Position**	⊙
GROUND VECTOR (TR-GS) **Track and ground speed**	——>>——	**Air Position**	+
WIND VECTOR (W/V) **Wind direction and speed**	——>>>——	**Fix**	◬

Figure 5-1. Standard Plotting Symbols

True Course (TC) is the intended horizontal direction of travel over the surface of the earth, expressed as an angle measured clockwise from true north (000°) through 360 degrees.

Course Line is the horizontal component of the intended path of the aircraft comprising both direction and magnitude or distance.

Track (Tr) is the horizontal component of the *actual* path of the aircraft over the surface of the earth. Track may, but very seldom does, coincide with the true course or *intended* path of the aircraft. The difference between the two is caused by an inability to predict perfectly all inflight conditions.

True Heading (TH) is the horizontal direction in which an aircraft is pointed. More precisely, it is the angle measured clockwise from true north through 360 degrees to the longitudinal axis of the aircraft. The difference between track and true heading is caused by wind and is explained under wind triangles.

Groundspeed (GS) is the rate of motion of the aircraft relative to the earth's surface or, in simpler terms, it is the speed of the aircraft over the ground. It may be expressed in nautical miles, statute miles, or kilometers per hour, but, as a navigator, you will use nautical miles per hour *(knots).*

True Airspeed (TAS) is the rate of motion of an aircraft relative to the air mass surrounding it. Since the air mass is usually in motion in relation to the ground, airspeed and groundspeed seldom are the same.

Dead Reckoning Position (DR position) is a point in relation to the earth established by keeping an accurate account of time, groundspeed, and track since the last known position. It may also be defined as the position obtained by applying wind effect to the true heading and true airspeed of the aircraft.

A **Fix** is an accurate position determined by one of the aids to DR.

Air Position (AP) is the location of the aircraft in relation to the air mass surrounding it. True heading and true airspeed are the components of the vector used to establish an air position.

Most Probable Position (MPP) is a position determined with partial reference to a DR position and partial reference to a fixing aid.

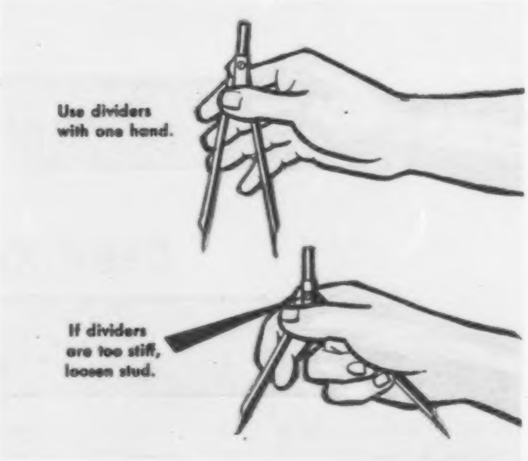

Use dividers with one hand.
If dividers are too stiff, loosen stud.

Figure 5-2. Use of Dividers

Plotting Equipment

Pencil and Eraser. Probably the most elementary but indispensable articles of plotting equipment are pencils and erasers. The pencil should be fairly soft and well sharpened. A hard pencil is undesirable, not only because it makes lines which are light and difficult to see, but also because it makes lines which are difficult to erase. An experienced navigator keeps his chart clean by erasing all unnecessary lines. It is good practice to carry several well-sharpened wooden pencils rather than a mechanical pencil. Mechanical pencils generally make broader, less precise lines.

Use a soft eraser which will not smudge or damage the chart. Hard, gritty erasers tend to wear away printed information as well as the paper itself. Not all erasers will remove all pencil lines, so find a pencil-eraser combination that will work satisfactorily. Nothing reflects a navigator's ability more than keeping neat, clean, and accurate charts and logs. An untidy chart, smudged and worn through in places, often causes one to conclude that the navigation performed was careless.

Dividers. A pair of dividers is an instrument used for measuring distances on a chart by separating the points of the dividers to the desired distance on the proper scale (usually the latitude scale) and transferring this distance to the working area of the chart. In this way, lines of a desired length can be marked off. By reversing

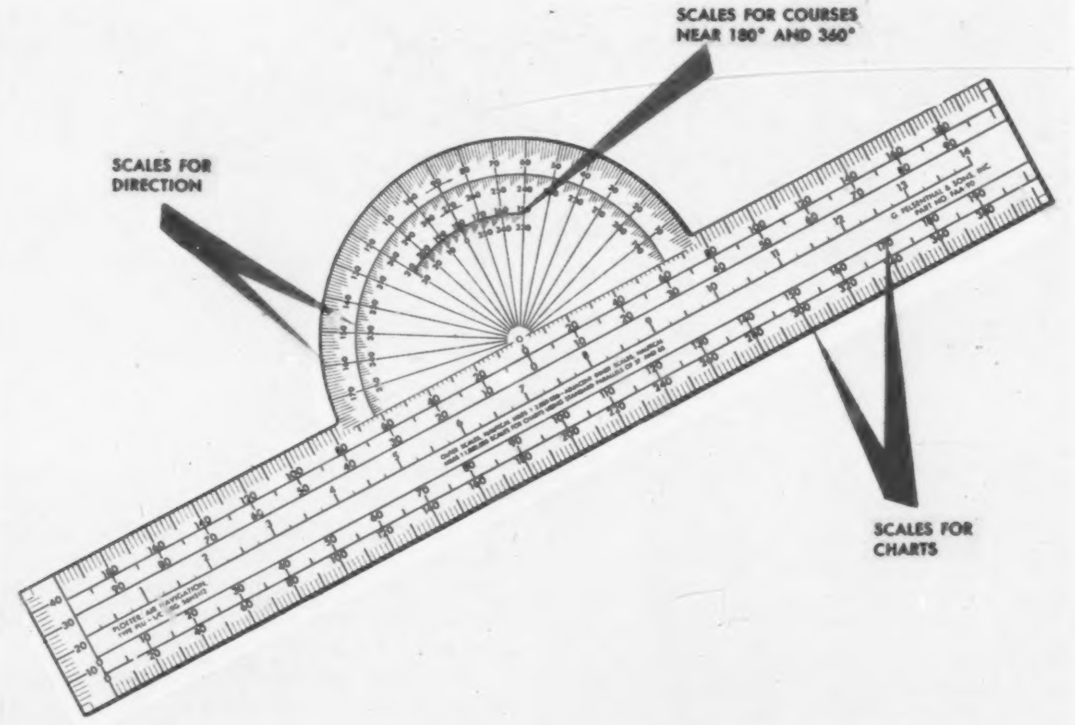


Figure 5-3. Typical Plotter

the process, unknown distances on the chart can be spanned and compared with the scale.

It is desirable to manipulate the dividers with one hand (see figure 5-2), leaving the other free to use the plotter, pencil, or chart as necessary. Most navigation dividers have a tension screw which you can adjust to prevent the dividers from becoming either too stiff or too loose for convenient use. Adjust the points of the dividers to approximately equal length. A small screw driver, required for these adjustments, should be a part of the navigator's equipment.

While making the measurement, hold the chart flat and smooth between the points of the dividers, as a wrinkle may cause an error of several miles. Mark points on a chart by applying slight pressure on the dividers so that they prick the chart. Too much pressure results in large holes in the chart and tends to spread the points of the dividers farther apart, reducing measurement accuracy. Precision navigation requires precision measurement.

PLOTTERS. A plotter is an instrument designed primarily to aid in drawing and measuring lines in desired directions. Plotters vary from complicated drafting machines and complete navigator's drafting sets to a simple plotter combining a kind of protractor and straight edge.

A common Air Force plotter is shown in figure 5-3. This plotter is a semicircular protractor with a straight edge attached to it. A small hole at the base of the protractor portion indicates the center of the arc of the angular scale. Two complete scales cover the outer edge of the protractor and are graduated in degrees. An abbreviated, inner scale measures the angle from the vertical.

The outer scale increases from 000 degrees to 180 degrees counterclockwise, and the inner

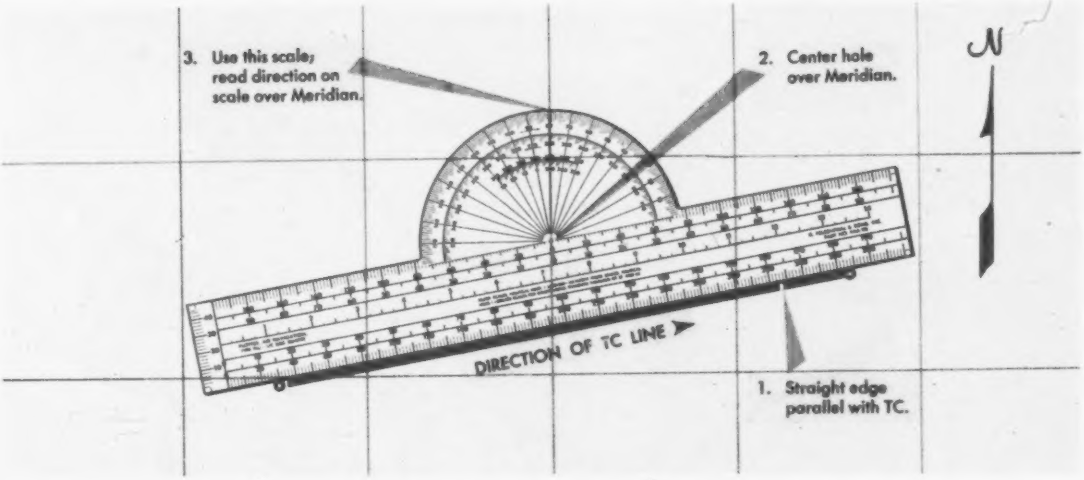

3. Use this scale; read direction on scale over Meridian.
2. Center hole over Meridian.
N
DIRECTION OF TC LINE
1. Straight edge parallel with TC.

Figure 5-4. To Measure True Course

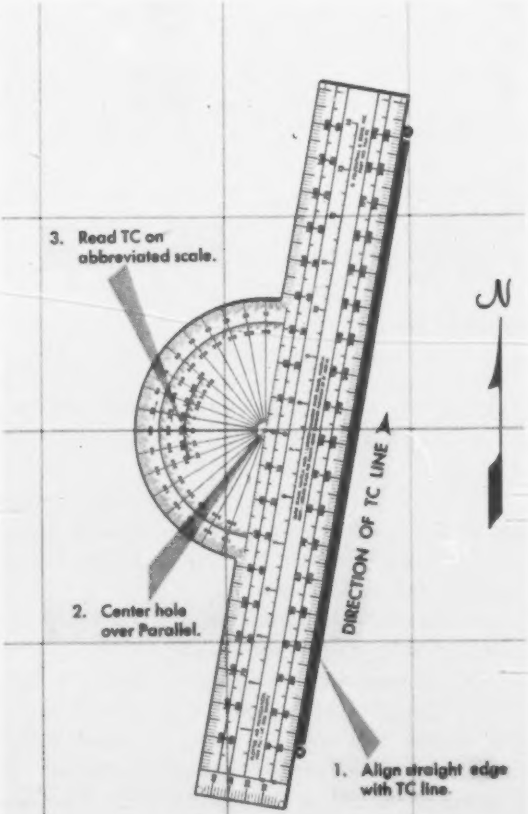

3. Read TC on abbreviated scale.
N
DIRECTION OF TC LINE
2. Center hole over Parallel.
1. Align straight edge with TC line.

Figure 5-5. To Measure True Course Near 180° or 360°

scale increases from 180 degrees to 360 degrees counterclockwise. An angle is measured by placing the vertical line (that line containing the small hole) on a meridian, and aligning the base of the plotter with the line to be measured as shown in the illustrations measuring true course (figures 5-4 and 5-5).

The angle measured is the angle between the meridian and the straight line. The outer scale is used to read all angles between north through east to south, and the inner scale is used to read all angles between south through west to north as in figure 5-6.

Plotting Procedure, Mercator Chart

PREPARATION. A great many charts and plotting sheets are printed on the Mercator projection. When plotting work is done on a blank plotting sheet, with only the parallels of latitude and the meridians printed on it, the plotting sheet should be oriented correctly depending upon the latitude. If the chart is to be used in south latitudes, the sheet is turned upside down so that the latitude increases toward the south.

When plotting on charts which have only the parallels printed on them, the meridians should be assigned the appropriate values for the longitude of the flight. With *North* at the top of the chart, west longitude increases toward the western (left) edge and east longitude increases toward the eastern (right) edge. This is true in both

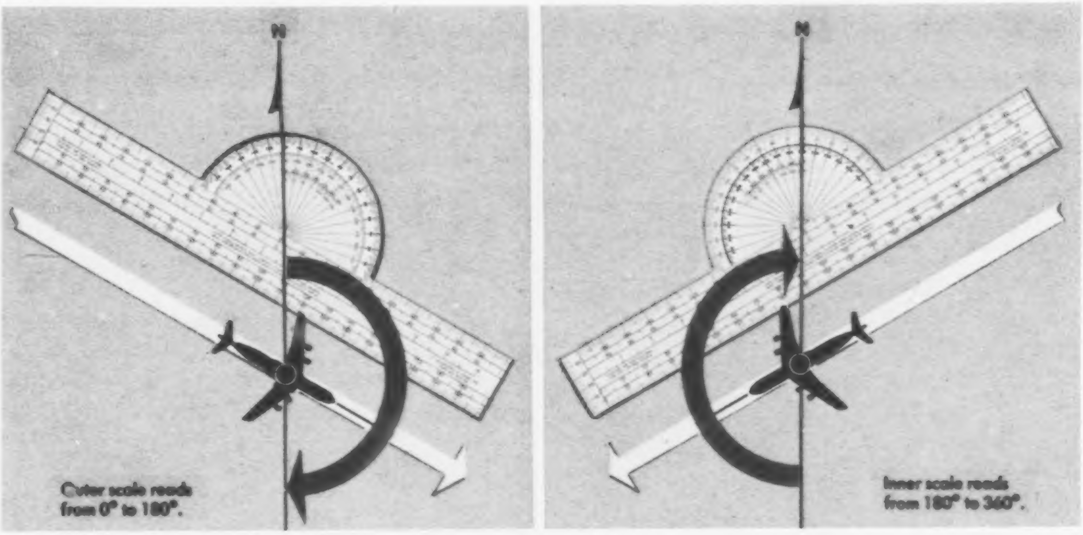

N
Outer scale reads from 0° to 180°.
N
Inner scale reads from 180° to 360°.

Figure 5-6. To Read Angles from Plotter

north and south latitudes. However, with *South* at the top of the chart, west longitude increases to the right and east longitude increases to the left. Once the meridians are numbered, the points of departure and destination should be plotted, along with important navigation aids.

Before starting any plot, note the scale and projection of the chart and check the date to make sure that it is the latest edition. The latitude scale is used to represent nautical miles. The longitude scale should never be used to measure distance. Some charts carry a linear scale in the margin, and, where present, it indicates that the same scale may be used anywhere on the chart.

PLOTTING POSITIONS. On some Mercator charts, the spacing between meridians and parallels is close enough to permit plotting by visual interpolation. However, on most Mercator charts, the meridians and parallels are more widely spaced, necessitating the use of dividers. There are several methods by which positions can be plotted on Mercator charts. One method is illustrated in figure 5-7. Place the straight edge of the plotter in a vertical position, at the desired longitude. Set the dividers to the desired number of minutes of latitude. Hold one point against the straight edge on the parallel of latitude corresponding to the whole degree of latitude given. Let the other point also rest against the straight edge and lightly prick the chart. This marks the desired position. In measuring the latitude and

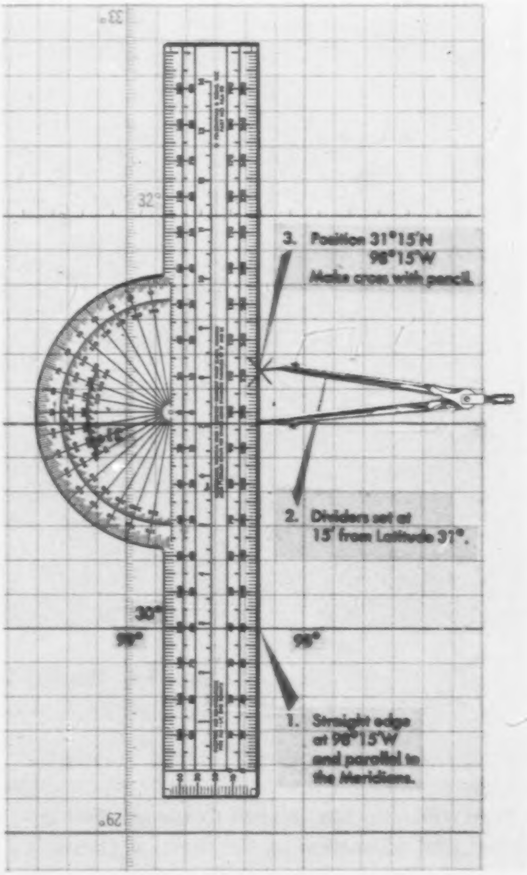

33°
32°
3. Position 31°15'N
98°15'W
Make cross with pencil.
2. Dividers set at
15' from Latitude 31°.
30°
98°
98°
1. Straight edge
at 98°15'W
and parallel to
the Meridians.
29°

Figure 5-7. Plotting Positions on a Mercator

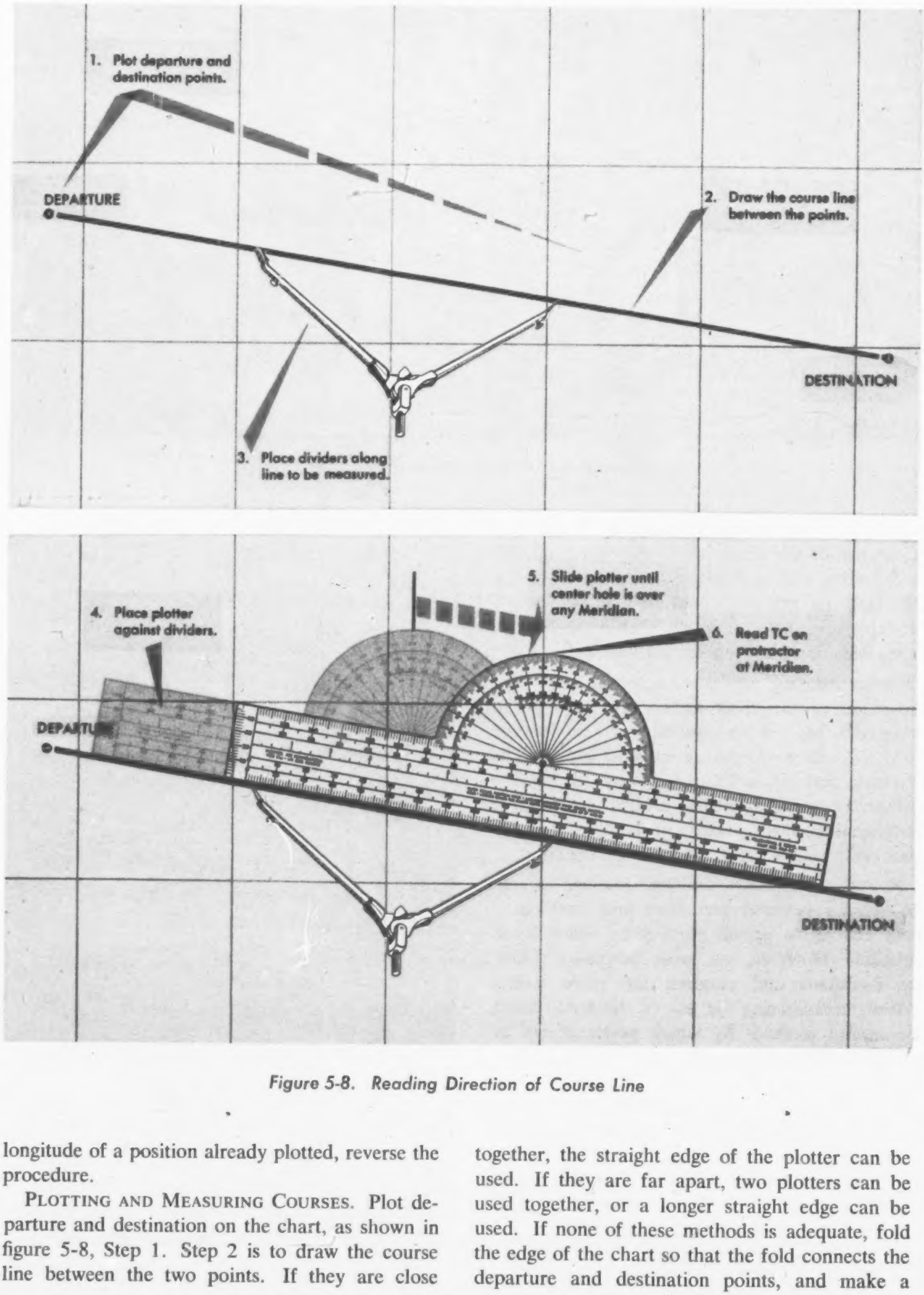

1. Plot departure and destination points.
DEPARTURE
2. Draw the course line between the points.
3. Place dividers along line to be measured.
DESTINATION
4. Place plotter against dividers.
5. Slide plotter until center hole is over any Meridian.
6. Read TC on protractor at Meridian.
DEPARTURE
DESTINATION

Figure 5-8. Reading Direction of Course Line

longitude of a position already plotted, reverse the procedure.

PLOTTING AND MEASURING COURSES. Plot departure and destination on the chart, as shown in figure 5-8, Step 1. Step 2 is to draw the course line between the two points. If they are close together, the straight edge of the plotter can be used. If they are far apart, two plotters can be used together, or a longer straight edge can be used. If none of these methods is adequate, fold the edge of the chart so that the fold connects the departure and destination points, and make a series of pencil marks along the edge. A plotter or straight edge can then be used to connect the points when the chart is unfolded.

After the course line has been plotted and labeled, the next step is to determine its direction. Place the points of the dividers or a pencil anywhere along the line to be measured, Step 3. Place the plotter against the dividers, Step 4. Slide the plotter until the center hole is over any meridian as shown in Step 5. Read TC on the protractor at the meridian, Step 6. Keep in mind the approximate direction of the line when reading the protractor.

A course line has two possible directions (figure 5-9): the correct one and the opposite or reciprocal. The error of plotting and measuring reciprocals is, unfortunately, all too common, and such mistakes have resulted in serious trouble for more than one navigator. By having a mental picture of the compass rose, the navigator can save himself the embarrassment of plotting or measuring reciprocal courses or bearings. Small arrows are found on some plotters near the 90°-270° marks to minimize the possibility of reading the wrong scale.

Measuring Nearly Vertical Lines. Sometimes the line whose direction is to be measured runs nearly north or south, making it difficult to align the hole in the plotter with a meridian. In this case, the easiest solution is to use a parallel of latitude as a reference instead of a meridian. Move the plotter along a line until the center hole is over any parallel of latitude. Measure the direction of the line by reading the degree scale on the same parallel and mentally adding or subtracting 90 degrees. Some plotters are provided with an abbreviated scale for measuring such angles without adding or subtracting 90 degrees.

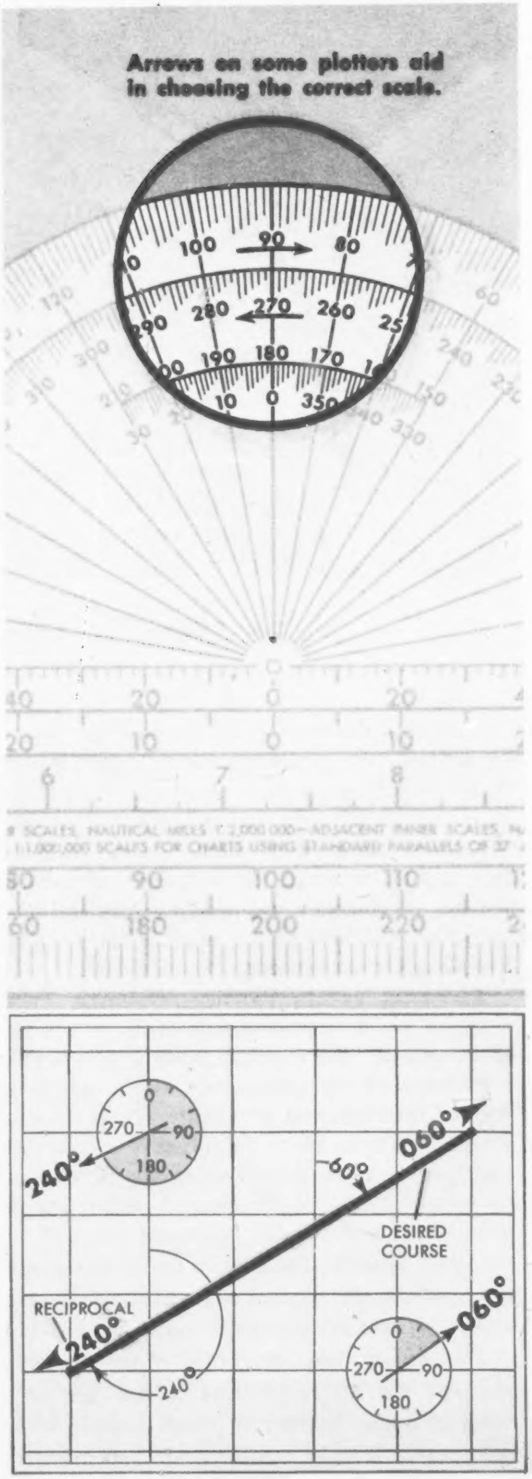


Figure 5-9. Reciprocal Directions

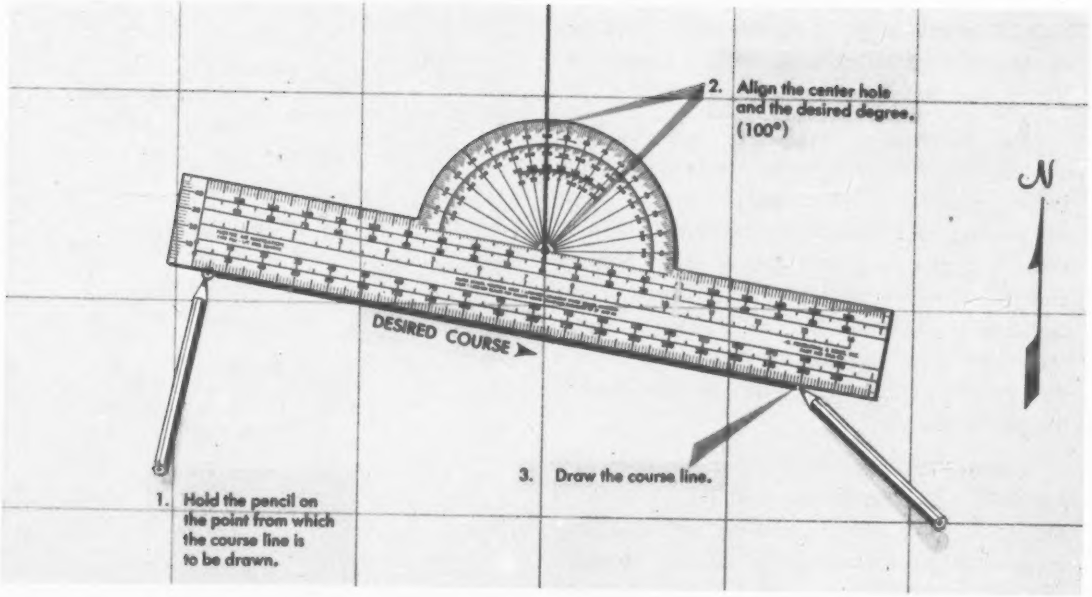

2. Align the center hole and the desired degree. (100°)
N
DESIRED COURSE
3. Draw the course line.
1. Hold the pencil on the point from which the course line is to be drawn.

Figure 5-10. Plotting Course from Given Position

PLOTTING COURSES FROM GIVEN POSITION. A course from a given position can be plotted quickly in the following manner: Place the point of a pencil on the position and slide the plotter along this point, rotating it as necessary, until the center hole and the figure on the protractor representing the desired direction are lined up with the same meridian. Hold the plotter in place and draw the line along the straight edge (figure 5-10).

PLOTTING NEARLY VERTICAL COURSES. When a course which extends nearly north or south is to be plotted, the simplest method of orienting a plotter is to align the plotter with a parallel of latitude, as explained previously. Hold a pencil on the point from which the course is to be drawn, and then slide the plotter along the pencil until the center hole and the desired degree on the abbreviated scale of the protractor are both on the same parallel. The edge of the plotter against the pencil is now aligned with the desired course and the course line can be drawn. (figure 5-11).

MEASURING DISTANCE. One of the disadvantages of the Mercator chart is the lack of a constant scale. If the two points between which the distance is to be measured are approximately in a north-south direction and the total distance between them can be spanned, the distance can be measured on the latitude scale opposite the midpoint. However, the total distance between any two points that do not lie approximately north or south of each other should not be spanned unless the distance is short. All distances should be measured as near the midlatitude as possible.

In the measurement of long distances, select a midlatitude lying approximately half-way between the latitudes of the two points. By using dividers set to a convenient, reasonably short distance, such as 60 nautical miles picked ~~off~~ at the midlatitude scale, you may determine an approximate distance by marking off units along the line to be measured as shown in figure 5-12.

The scale at the midlatitude is accurate enough if the course line does not cover more than 5 degrees of latitude (somewhat less in high latitudes). If the course line exceeds this amount or if it crosses the equator, divide it into two or more legs and measure the length of each leg with the scale of its own midlatitude.

Plotting Procedure, Lambert Conformal and Gnomonic Charts

PLOTTING POSITIONS. On a Lambert conformal chart, the meridians are not parallel as on a Mercator chart. Therefore, in plotting a position

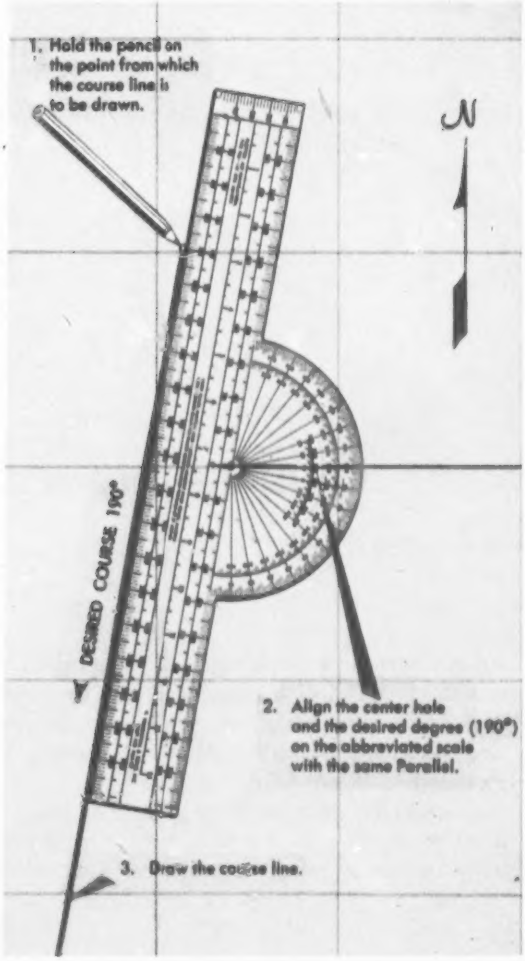

1. Hold the pencil on the point from which the course line is to be drawn.
N
DESIRED COURSE 190°
2. Align the center hole and the desired degree (190°) on the abbreviated scale with the same Parallel.
3. Draw the course line.

Figure 5-11. Plotting Nearly Vertical Courses

by the method described under Mercator charts, it is not accurate to allow the plotter to parallel any one printed meridian. Instead, the plotter should intersect two graduated *parallels* of *latitude* at the desired longitude. When the plotter is in this position, the dividers are set to the given minutes of latitude, and with one point resting on the given parallel of latitude against the plotter, the other point will rest on the correct position adjacent to the plotter. Follow this procedure on a small scale chart where the meridians show marked convergence. On a large scale chart, the meridians are so nearly parallel that this precaution is unnecessary.

The scale on all parts of a Lambert conformal chart is essentially constant. Therefore, it is not absolutely necessary to pick off minutes of latitude near any particular parallel except in the most precise work. Distances can be measured using any portion of the latitude scale, or by using the miles scale which is usually shown.

Plotting and Measuring Courses. Any straight line plotted on a Lambert conformal chart is approximately an arc of a great circle. In long distance flights, this feature is advantageous since the great circle course line can be plotted as easily as a rhumb line on a Mercator chart.

However, for shorter distances where the difference between the great circle and rhumb line is negligible, the rhumb line is more desirable because a constant heading can be held. For such

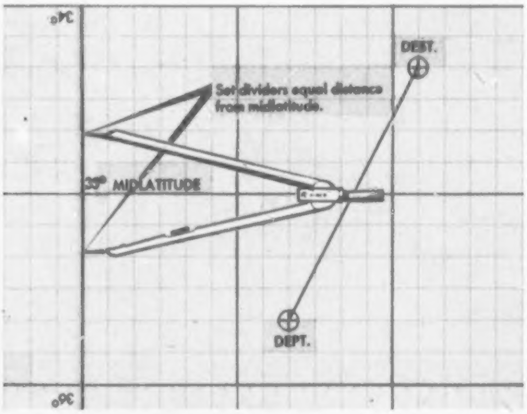

34°
DEST.
Set dividers equal distance from midlatitude.
35° MIDLATITUDE
DEPT.
36°

Figure 5-12. Midlatitude Scale

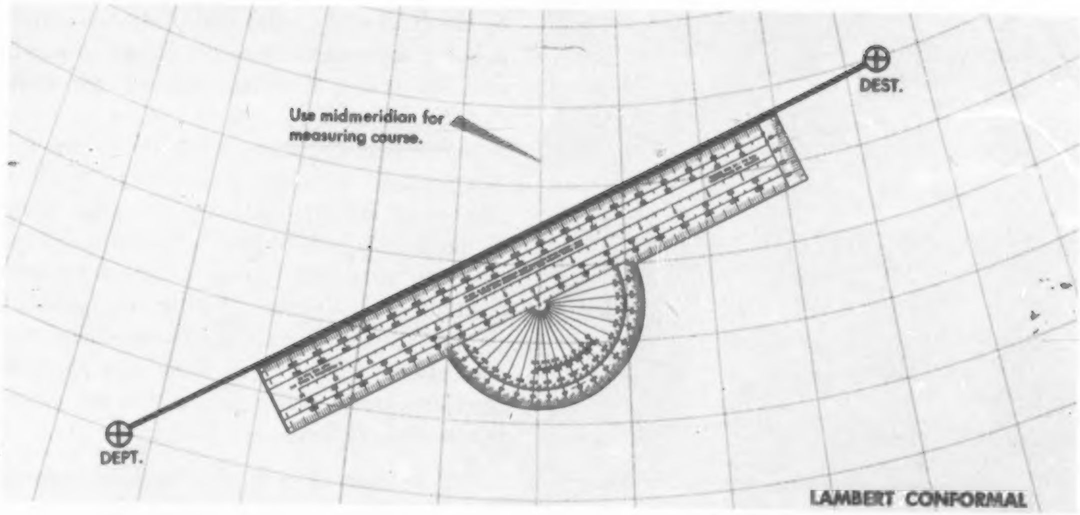

Use midmeridian for measuring course.
DEST.
DEPT.
LAMBERT CONFORMAL

Figure 5-13. Use Midmeridian to Measure Course on a Lambert Conformal

distances, the approximate direction of the rhumb line course can be found by measuring the great circle course at midmeridian as shown in figure 5-13. In this case, the track is not quite the same as that indicated by the course line drawn on the chart, since the actual track (a rhumb line) appears as a curve convex to the equator on a Lambert conformal chart, while the course line (approximately a great circle) appears as a straight line. Near midmeridian, the two have approximately the same direction (except for very long distances) along an oblique course line as indicated in figure 5-14.

For long distances involving great circle courses, it is not feasible to change heading continually, as is necessary when following a great circle

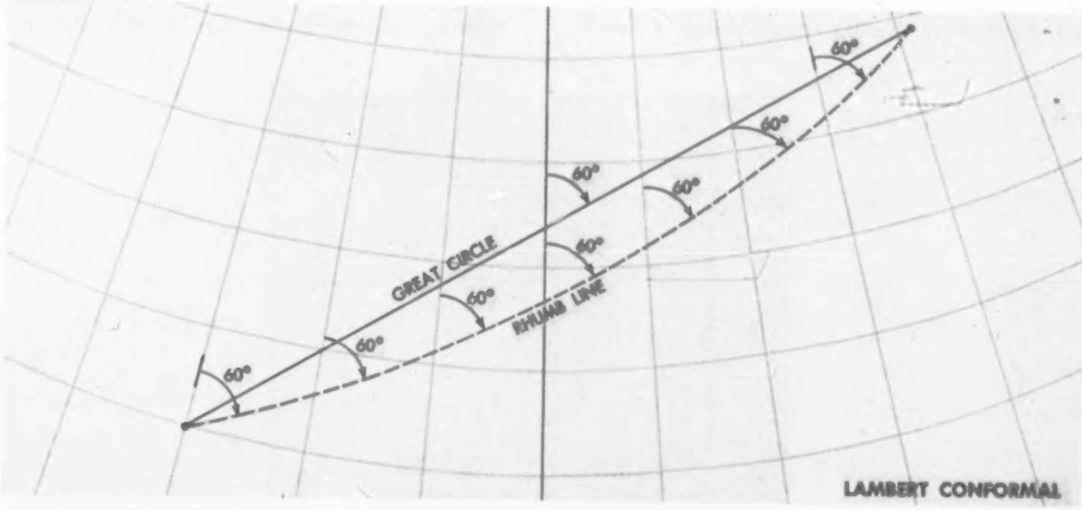

60°
60°
60°
60°
60°
60°
60°
60°
GREAT CIRCLE
RHUMB LINE
LAMBERT CONFORMAL

Figure 5-14. At Midmeridian, Rhumb Line and Great Circle Have Approximately the Same Direction

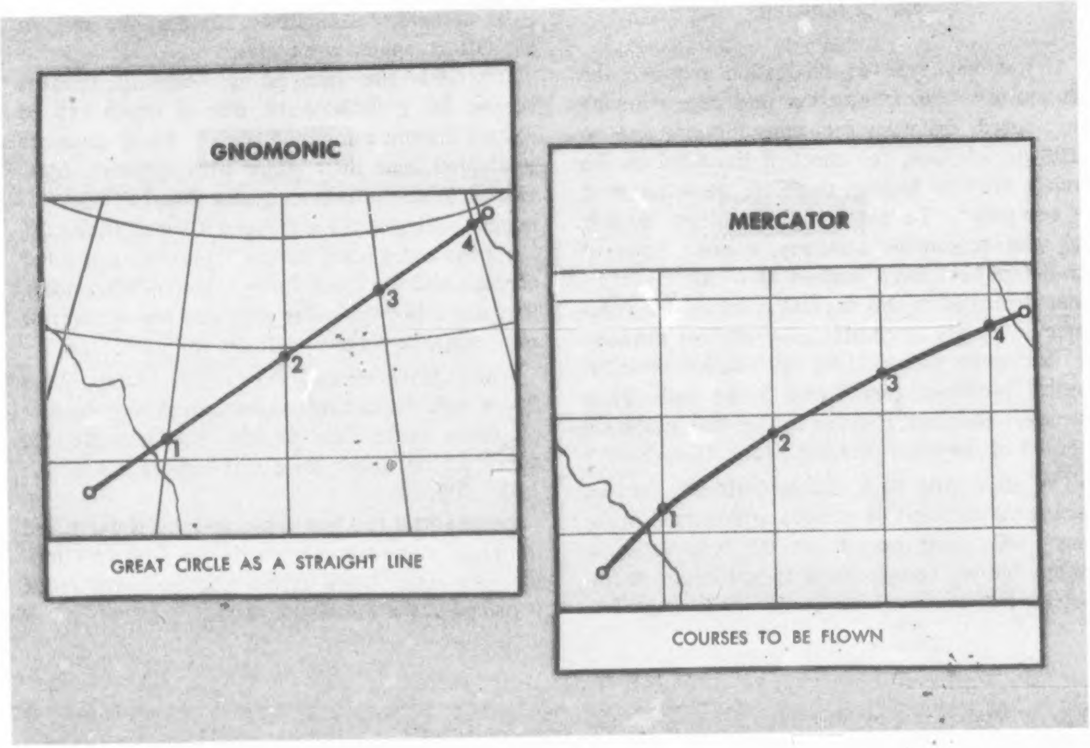


Figure 5-15. Transferring Great Circle Route from Gnomonic to Mercator Chart

exactly, and it is customary to divide the great circle into a series of legs, each covering about 5 degrees of longitude. The direction of the rhumb line connecting the ends of each leg is found at its midmeridian.

MEASURING DISTANCE. As previously stated, the scale on a Lambert conformal chart is practically constant, making possible the use of any part of a meridian graduated in minutes of latitude for measurement of nautical miles. Scales of both nautical and statute miles are shown on some Lambert conformal charts.

PLOTTING ON A GNOMONIC CHART. Gnomonic charts are used mostly for planning great circle routes. Since any straight line on a gnomonic chart is an arc of a great circle, a straight line from the point of departure to destination indicates the great circle route. This great circle route is customarily used by transferring the line in segments to a Mercator chart as shown in figure 5-15.

The latitude and longitude of a series of points along the great circle are measured and plotted on a Mercator chart. They are then connected with straight (rhumb) lines.

PLOTTING HINTS. The following suggestions should prove helpful in developing good plotting procedure:

- Measure all directions and distances carefully. Check and doublecheck all measurements, computations, and positions.
- Avoid plotting unnecessary lines. If a line serves no purpose, erase it. Do not allow lines to extend beyond their useful limits.
- Keep plotting equipment in good working order. If the plotter is broken, replace it. Keep sharp points on dividers. Use a sharp-pointed, soft pencil and an eraser that will not smudge.
- Draw light lines at first, as they may have to be erased. When the line has been checked and proven to be correct, then darken it if desired.
- Hold the pencil against the plotter at the same angle throughout the entire length of the line.
- Label lines and points immediately after they are drawn. Use standard labels and symbols. Letter the labels legibly. Be neat and exact.

DR COMPUTER

Almost any type of navigation requires the solution of simple arithmetical problems involving time, speed, distance, fuel consumption, and so forth. In addition, the effect of the wind on the aircraft must be known; therefore the wind must be computed. To solve such problems quickly and with reasonable accuracy, various types of computers have been devised of which the computer described in this manual is one. This computer is simply a combination of two devices: (1) a circular slide rule for the solution of arithmetical problems (See figure 5-16) and (2) a specially designed instrument for the graphical solution of the wind problem. (See figure 5-17.)

The slide rule is a standard device for the mechanical solution of various arithmetical problems. Slide rules operate on the basis of logarithms, but no knowledge of logarithms is necessary for the successful use of the instrument. Slide rules are either straight or circular; the one on the DR computer is circular.

The slide rule face of the computer consists of two flat metallic disks, one of which can be rotated around a common center. These disks are graduated near their edges with adjacent, logarithmic scales to form a circular slide rule approximately equivalent to a straight, 12-inch slide rule. Since the outer scale usually represents a number of miles and the inner scale, a number of minutes, they are called the *miles scale* and the *minutes or time scale,* respectively. Refer to figure 5-16.

The numbers on each scale represent the printed figure with the decimal point moved any number of places to the right or left. For example, the figure 12 on either scale can represent 1.2, 12, 120, 1200, etc.

Since speed (or fuel consumption) is expressed in miles (or gallons or pounds) *per hour* (60 minutes), a large, black arrow marked *speed index* is placed at the 60-minute mark.

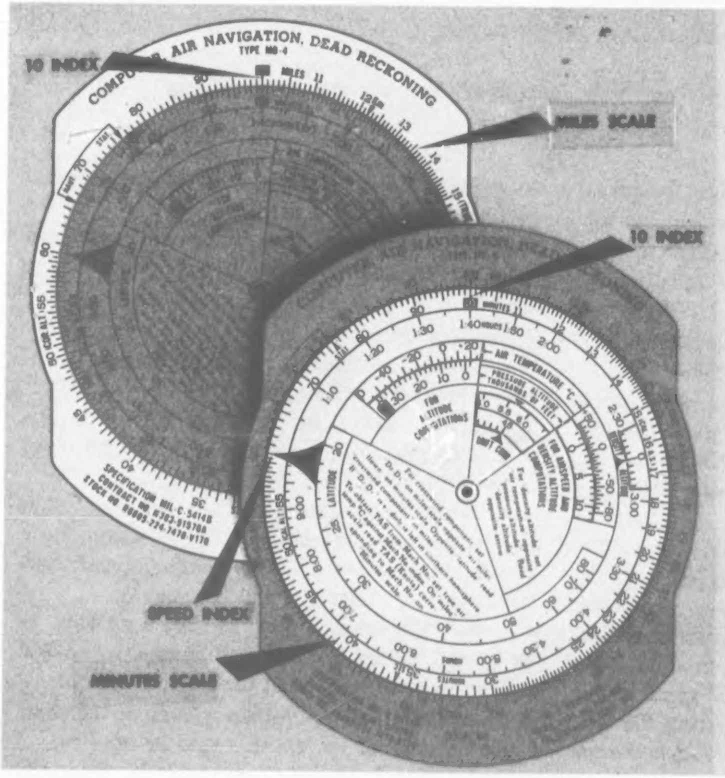


Figure 5-16. DR Computer Slide Rule Face

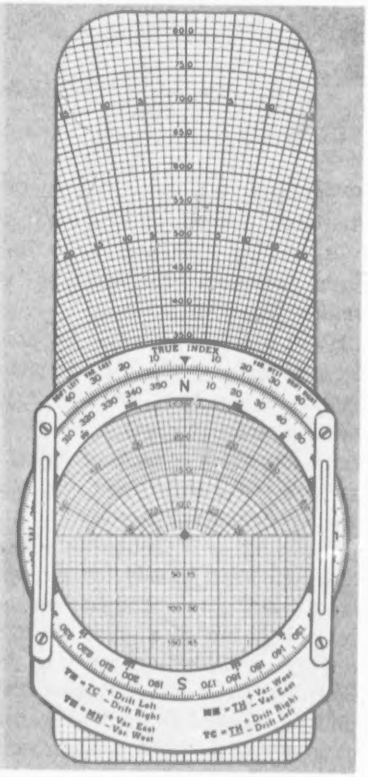
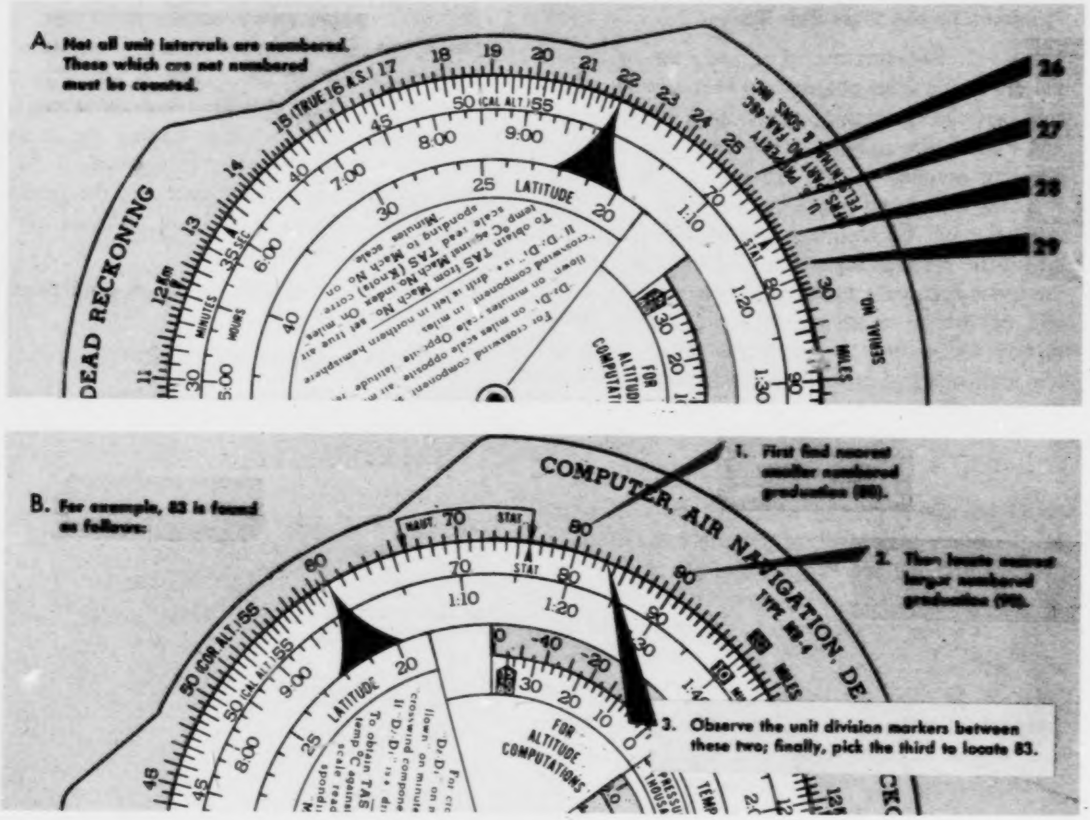


Figure 5-17. DR Computer Wind Face



A. Not all unit intervals are numbered. Those which are not numbered must be counted.

B. For example, 83 is found as follows:

1. First find nearest smaller numbered graduation (80).

2. Then locate nearest larger numbered graduation (90).

3. Observe the unit division markers between these two; finally, pick the third to locate 83.

Figure 5-18. Reading the Slide Rule Face

Graduations of both scales are identical. The graduations are numbered from 10 to 100 and the unit intervals decrease in size as the numbers increase in size. Not all unit intervals are numbered. The first element of skill in using the computer is a sure knowledge of how to read the numbers.

Reading the Slide Rule Face

The unit intervals which are numbered present no difficulty. The problem lies in giving the correct values to the many small lines which come between the numbered intervals. There are no numbers given between 25 and 30 as shown in figure 5-18A, for example, but it is obvious that the larger intermediate divisions are 26, 27, 28, and 29. Between 25 and (unnumbered) 26, there are five smaller divisions, each of which would therefore be .2 of the larger unit.

To find an uneven number, such as 83, illustrated in figure 5-18B, find first the nearest smaller numbered graduation (80), then the nearest larger numbered graduation (90). After observing the value of the divisions between, select the proper division (in this case, the third) for the desired number.

For a number such as 278, first find the 27 (for 270), then the 28 (for 280), then the fourth of the intermediate divisions (for 278) since the divisions here are of two units each. Obviously, unit divisions will be found only for numbers made up of relatively few integers. For a number such as 27812, the point already chosen for 278 would be used. This same point would also be used for 27.8, 2.78, etc. There are thus several numbers for each point on the scale. The matter of the use and place of the decimal point is largely one of common sense.

Problems on the Slide Rule Face

SIMPLE PROPORTION. The slide rule face of the computer is so constructed that any relationship between two numbers, one on the miles scale and one on the minutes scale, will hold true for all other numbers on the two scales. Thus, if the two 10's are placed opposite each other, all other numbers will be identical around the circle. If 20 on the minutes scale is placed opposite 10 on the miles scale, all numbers on the minutes scale will be double those on the miles scale. This feature allows one to supply the fourth term of any mathematical proportion. Thus, the unknown in the equation

$$\frac{18}{45} = \frac{x}{80}$$

could be solved on the computer by setting 18 on the miles scale over 45 on the minutes scale and reading the answer (32) above the 80 on the minutes scale. It is this relationship that makes possible the solution of time-speed-distance problems.

TIME, SPEED, AND DISTANCE. An aircraft has traveled 24 miles in 8 minutes. How many minutes will be required to travel 150 miles? This is a simple proportion which can be written as

$$\frac{24}{8} = \frac{150}{x}$$

Setting the 24 over the 8 on the computer as illustrated in figure 5-19 and reading under the 150, we find the answer to be 50 minutes.

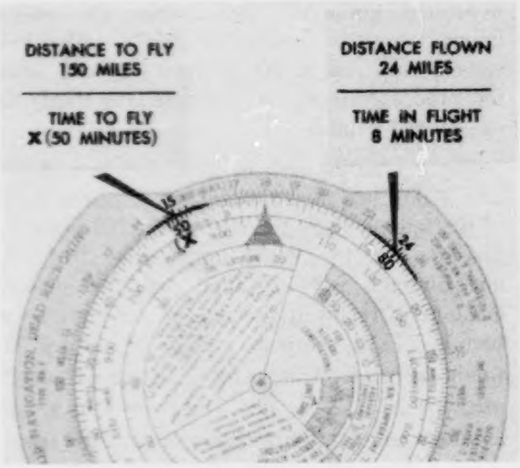


Figure 5-19. Solve for X

A problem that often occurs is to find the groundspeed of the aircraft when a given distance is traveled in a given time. This is solved in the same manner, except that the computer is marked with a speed index to aid in finding the correct proportion. In the problem just stated, if 24 is set over 8 as in the original problem, the groundspeed of the aircraft, 180 knots, is read above the speed index as shown.

Example: To find distance when groundspeed and time are known.

Given: Groundspeed 204 knots.

Required: Distance traveled in 1 hour 15 minutes (75 minutes).

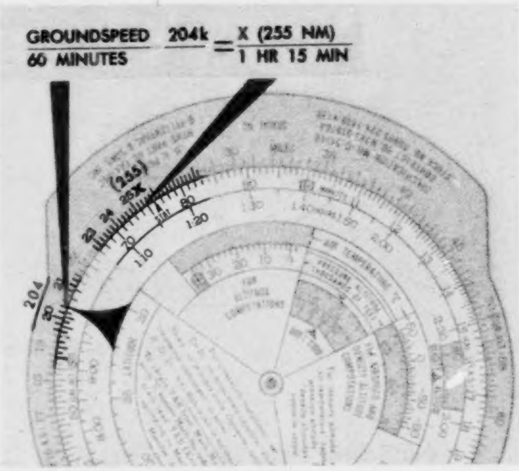


Figure 5-20. To Find Distance when Speed and Time Are Known

Solution: Set the speed index on the minutes scale to 204 on the miles scale. Opposite 75 on the minutes scale, read 255 nautical miles on the miles scale. The computer solution is shown in figure 5-20.

Example: To solve for time when speed and distance are given.

Given: Groundspeed 250 knots
Distance 375 miles

Required: Time

Solution: Set speed index on the minutes scale opposite the groundspeed (250 knots) on the

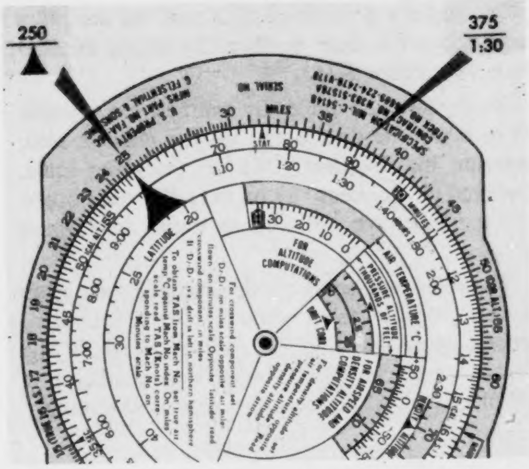


Figure 5-21. To Find Time when Speed and Distance Are Known

Figure 5-22. To Find Speed when Time and Distance Are Known

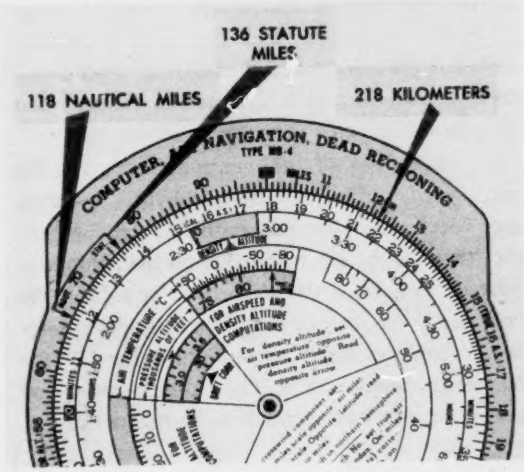


Figure 5-23. Statute Mile, Nautical Mile, Kilometer Interconversion

miles scale. Opposite the distance (375) on the miles scale read the time (1:30) on the minutes scale. In this instance, the hours scale beneath the minutes scale is used since the time is more than one hour. The minutes scale reads correctly in minutes (90 minutes) but the hours scale converts the time into hours and minutes. The computer solution is shown in figure 5-21.

Example: To find speed when time and distance are known.

Given: Distance 140 nautical miles
Time 40 minutes

Required: Groundspeed

Solution: Set the distance (140) on the miles scale above the time (40) on the minutes scale. Read the groundspeed (210 knots) above the speed index on the minutes scale as shown in figure 5-22.

SECONDS INDEX. Since one hour is equivalent to 3600 seconds, a subsidiary index mark, called *seconds index,* is marked at 36 on the minutes scale of some computers. When placed opposite a speed on the miles scale, the index relates the scales for converting distance to time in seconds. Thus, if 36 is placed opposite a groundspeed of 144 knots, 50 seconds is required to go two nautical miles, and in 150 seconds (2 minutes 30 seconds) 6.0 nautical miles are covered. Similarly, if four nautical miles are covered in 100 seconds, groundspeed is 144 knots.

CONVERSION OF DISTANCE. Subsidiary indexes are placed on some computers to aid in the conversion of distances from one unit of measure to another. The most common interconversions are those involving statute miles, nautical miles, and kilometers.

Statute-Nautical Mile Interconversion. The miles scale of the computer is marked with a statute mile index at 76 and a nautical mile index at 66. The units are interconverted by setting the known distance under the appropriate index and reading the desired unit under the other.

Example: To convert 136 statute miles to nautical miles, set 136 on the minutes scale under the STAT index on the miles scale. Under the NAUT index on the miles scale, read the number of nautical miles (118) on the minutes scale. See figure 5-23.

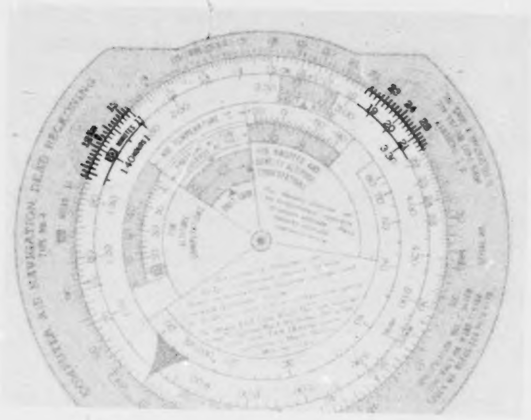


Figure 5-24. To Multiply Two Numbers

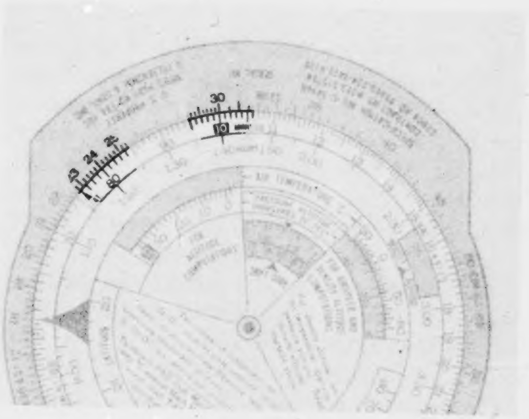


Figure 5-25. To Divide One Number by Another

Conversion of Nautical or Statute Miles to Kilometers. A kilometer index is indicated on the miles scale of the computer at 122. When nautical or statute miles are placed under their appropriate index on the miles scale, kilometers may be read, on the minutes scale, under the Km index.

Example: To convert 118 nautical miles to kilometers, place 118 on the minutes scale under the NAUT index on the miles scale. Under the KM index on the miles scale, read kilometers (218) on the minutes scale.

Multiplication and Division. To multiply two numbers, for example 12 × 2, the index (printed as 10 on the minute scale) is placed opposite one of the numbers to be multiplied (12), and the product (24) is read on the miles scale above the other number (2) on the minutes scale (see figure 5-24).

To divide one number by another, for example 24 ÷ 8, set the divisor (8) on the minutes scale opposite the dividend (24) on the miles scale, and read the quotient (3) on the miles scale opposite the index on the minutes scale (see figure 5-25).

The rules for placing the decimal point are given in most algebra texts. However, in the computations encountered in air navigation, as in the above examples, there is usually no doubt as to the placement of the decimal point in the result.

Review of the Slide Rule Face

The computer is a circular slide rule with two circular scales; the outer miles scale and the inner minutes scale. The inner scale is rotatable. A ratio exists around the slide rule so that when one ratio or fraction is set on the scale, this automatically sets up every possible fraction of equal value. Knowing one term of any fraction in the proportion, the other term is found either above or below the known term.

Use caution in positioning the decimal point in problems. The slide rule is based on logarithms; consequently, the numbers represent multiples of ten. The number 10 may represent 10,000 in one problem and only 100 in another, yet it is found in the same place. However, in most cases, the position of the decimal point will be fairly obvious.

Another thing to learn is the value of the graduations between numbers. In some cases it may be one, and in others two. When looking for uneven numbers, find the nearest smaller numbered graduation and the nearest larger numbered graduation and determine the value of the divisions in between. Then select the value desired.

The major use of the computer is in solving time, speed, and distance problems. Because time, speed, and distance problems are proportions, they can be solved quickly on the computer. Regardless of which unknown must be solved, the computer is set so that the distance appears over the time and the speed appears above the 60 (the arrowhead speed index). The number 60 is used because in most cases, values in knots are desired.

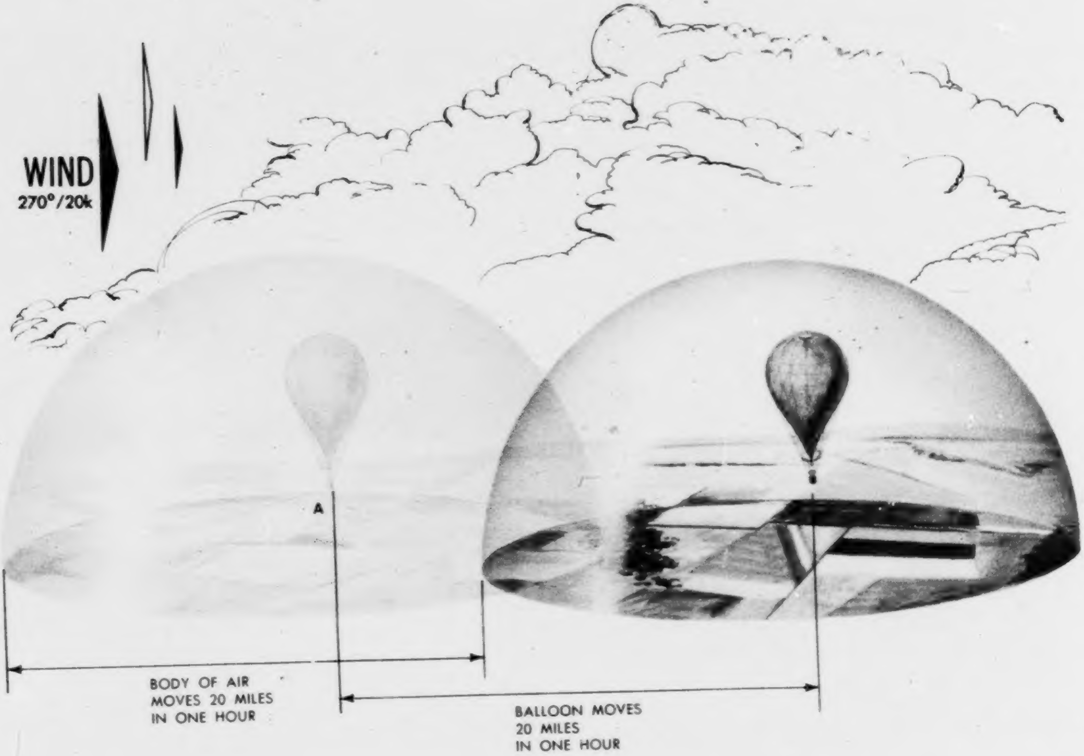

WIND
270°/20k
A
BODY OF AIR MOVES 20 MILES IN ONE HOUR
BALLOON MOVES 20 MILES IN ONE HOUR

Figure 5-26. Balloon Floats Downwind at Rate Equal to Wind Speed

To convert statute miles to nautical miles, or vice versa, there are convenient scales provided which eliminate the necessity for setting up a proportion. In addition, a kilometer conversion is provided.

To solve a problem of multiplication or division, set the equation on the computer as a proportion. For multiplication, set the index under one factor and read the product over the other factor. For division, the divisor is placed under the number to be divided and the answer is read above the index.

The use of the windows on the slide rule side of the computer is covered later.

EFFECT OF WIND ON AIRCRAFT

Any vehicle traveling on the ground, such as an automobile, moves in the direction in which it is steered or headed and is affected very little by wind. However, an aircraft seldom travels in exactly the direction in which it is headed because of the wind effect.

Consider first the effect of wind on a balloon which has no motion of its own. At 0900 a balloon is launched into the air at point *A* in figure 5-26. If the wind is from 270 degrees at 20 knots (W/V, 270°/20k), where is the balloon at 1000? Think of the balloon as floating in a body of air which moves from 270 degrees toward 90 degrees at 20 knots. In one hour the body of air moves 20 nautical miles and the balloon moves with it. Thus, in the illustration, at 1000 the balloon is at point *B*, 20 nautical miles from point *A* in the direction of 90 degrees. A balloonist never feels any wind because he is suspended in the body of air and moves with it. Consequently, no air moves past him. A balloon in the air is just like an empty bottle floating down a river; it travels with the current.

Any free object in the air moves downwind with the speed of the wind. This is just as true of an aircraft as it is of a balloon. If an aircraft is flying in a 20-knot wind, the body of air in which it is flying moves 20 nautical miles in one hour. Therefore, the aircraft also moves 20 nautical miles downwind in one hour. This move-

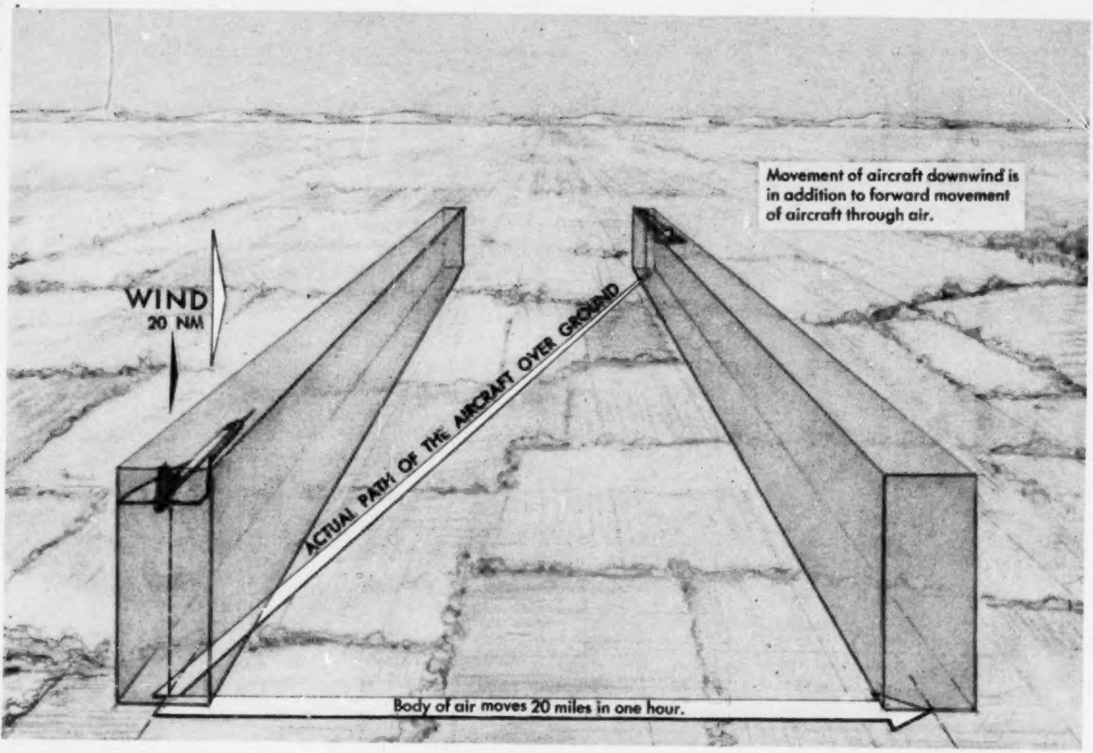

Movement of aircraft downwind is in addition to forward movement of aircraft through air.
WIND
20 NM
ACTUAL PATH OF THE AIRCRAFT OVER GROUND
Body of air moves 20 miles in one hour.

Figure 5-27. Two Factors Determine Path of Aircraft

ment is in addition to the forward movement of the aircraft through the body of air.

The path of an aircraft over the earth is determined by the two unrelated factors shown in figure 5-27: (1) the motion of the *aircraft through the air mass,* and (2) the motion of the *air mass* across the earth's surface. The motion of the aircraft through the air mass is directly forward in response to the pull of the propellers or thrust of the jet units, and its rate of movement through the air mass is true airspeed. This motion takes place in the direction of true heading. The motion of the air mass across the earth's surface may be from any direction and at any speed. The measurement of its movement is called wind and is expressed in direction and speed (W/V).

Drift Caused by Wind

An aircraft's movement over the ground is comparable to a boat crossing a river. If there is no current in the river, a boat started at one shore of the river and rowed perpendicularly to the river's edge would end up at a point on the opposite shore directly across from its starting point. However, if there is a current, the boat will be carried downstream. Until the boat eventually reaches the opposite shore, the displacement downstream is dependent upon the velocity of the river current and the speed of the boat.

The aircraft in figure 5-28 departs from point *A* on a heading of 360 degrees and flies for one hour in a wind of 270°/20k. The aircraft is headed toward point *B*, directly north of *A*, so its true heading is represented by the line *AB*. If there were no wind, the aircraft would be at point *B* at the end of the hour. However, there is a wind. The body of air in which the aircraft is flying moves 20 nautical miles toward the east in the hour, and the aircraft moves with it. Consequently, at the end of the hour the aircraft is at point *C*, 20 nautical miles downwind from point *B*. The line *AB* is the path of the aircraft through the body of air; the line *BC* shows the motion of the body of air; and the line *AC* is the actual path of the aircraft over the earth. The effect, then, of this wind on the aircraft is to

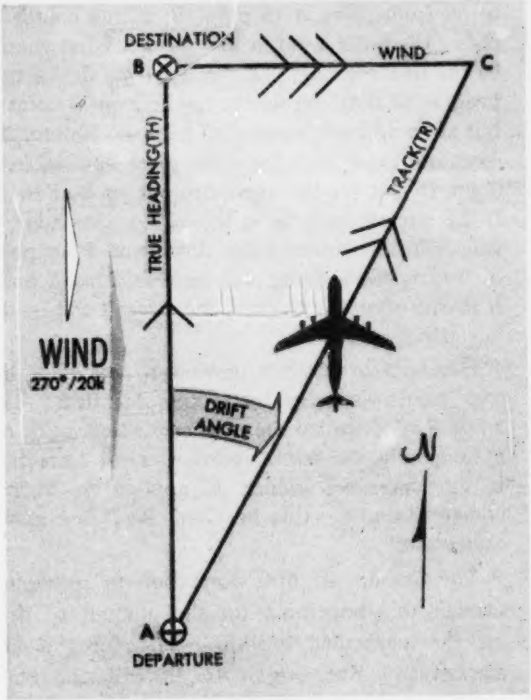

DESTINATION
B
WIND
C
TRUE HEADING(TH)
TRACK(TR)
WIND
270°/20k
DRIFT ANGLE
N
A
DEPARTURE

Figure 5-28. In One Hour, Aircraft Drifts Downwind an Amount Equal to Wind Speed

cause it to follow a different path over the ground than it does through the air mass. The path over the ground is its track (Tr). At this time it might be well to differentiate between the terms true course (TC) and track (Tr). True course represents the intended path of the aircraft over the earth's surface. Track is the actual path that the aircraft has flown over the earth's surface. The terms TC and Tr are often considered synonymous. Remember, however, that in the actual workings of navigation, true course is considered to be future, while track is considered to be past.

The lateral displacement of the aircraft caused by the wind is called *drift*. Drift is the angle between the true heading and the track. As shown in figure 5-28, the aircraft has drifted to the right; this is known as right drift.

With a given wind, the drift will change on each heading. A change of heading will also affect the distance flown over the earth's surface in a given time. This rate traveled relative to the earth's surface is known as groundspeed (GS). Therefore, with a given wind, the groundspeed (GS) varies on different headings.

The next illustration, figure 5-29, shows the effect of a 270°/20k wind on the groundspeed and track of an aircraft flying on headings of 000°,

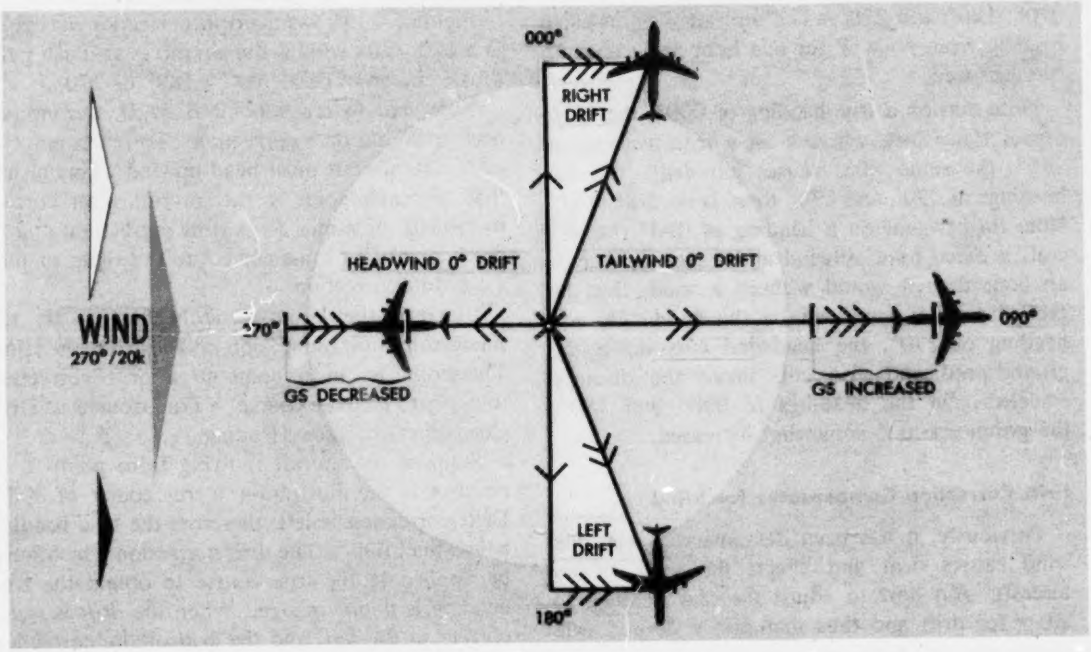

000°
RIGHT DRIFT
WIND
270°/20k
HEADWIND 0° DRIFT
TAILWIND 0° DRIFT
270°
090°
GS DECREASED
GS INCREASED
LEFT DRIFT
180°

Figure 5-29. Effect of Wind on Aircraft Flying in Opposite Directions

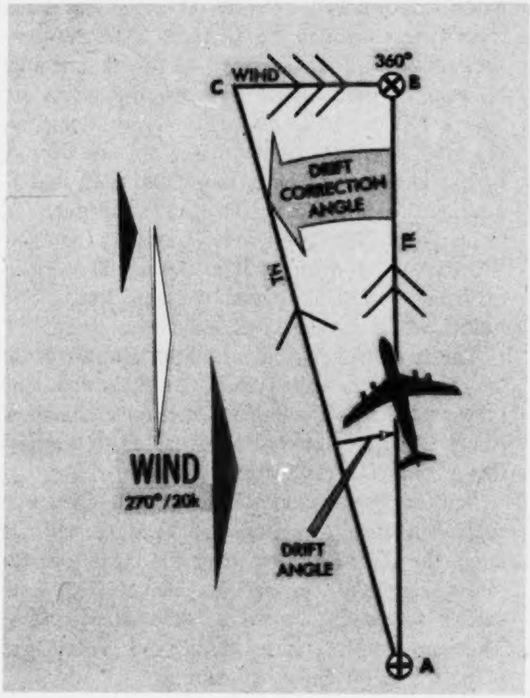


Figure 5-30. Aircraft Heads Upwind to Correct for Drift

090°, 180° and 270°. The aircraft flies on each heading from point *X* for one hour at a constant true airspeed.

Note that on a true heading of 000°, the wind causes right drift, whereas on a true heading of 180°, the same wind causes left drift. On the headings of 090° and 270° there is no drift at all. Note further that on a heading of 090° the aircraft is aided by a tailwind and travels farther in an hour than it would without a wind; thus its groundspeed is increased by the wind. On the heading of 270°, the headwind cuts down the groundspeed and also cuts down the distance traveled. On the headings of 000° and 180°, the groundspeed is somewhat increased.

Drift Correction Compensates for Wind

Previously, it has been demonstrated how the wind causes drift and affects the track of an aircraft. But how to adjust the true heading to allow for drift and thus maintain a desired true course has not been explained.

In figure 5-30 suppose the navigator wants to fly from point *A* to point *B*, a true course of 000°, when the wind is 270°/20k. What should be the true heading? Obviously, if he flew a true heading of 000° he would not end up at point *B* but at some point downwind from *B*. Rather, the navigator must head for some point *upwind* from point *B* and let the right drift bring him to *B*. If the aircraft is to be in the air for one hour, it will drift 20 nautical miles downwind from point *B*. Flying the heading *AC*, he would reach point *B* in one hour; the track of the aircraft will be the line *AB*.

Heading an aircraft upwind to maintain the true course is called correcting for drift. The angle *BAC* is called the *drift correction angle* or, more simply, the *drift correction*. Drift correction is the correction which is applied to a true course to find the true heading. *BAC* is a minus correction.

The amount of drift correction must be just enough to compensate for the amount of drift on the particular heading. Therefore, if the aircraft is on a heading of *AC*, the drift correction angle must be equal to the drift angle. If drift is to the right, drift correction must be to the left or minus. Therefore, the drift correction angle is measured in the opposite direction to the drift and given a sign of plus or minus.

Figure 5-31 shows the drift correction necessary in a 270°/20k wind if the aircraft is to make good a true course of 000°, 090°, 180° or 270°.

Note that to reach point *B* or *D*, the aircraft need make no drift correction. To reach point *A* or *C*, the aircraft must head upwind. This means that to reach point *A* the aircraft must correct to the left, or minus (—) drift correction, and to reach point *C* it must correct to the right, or plus (+) drift correction.

In computing a magnetic heading to fly the navigator must first obtain the true heading. Therefore, he must compute a drift correction to apply to the true course. (True Course $\mp$ Drift Correction = True Heading.)

Suppose an aircraft is flying from point *X* to point *A* in the illustration, a true course of 000°. Drift correction is left; therefore the true heading is less than 000°. The drift correction which must be applied to the true course to obtain the true heading is *minus* in sign. When the *drift* is *right*, *correct* to the *left*, and the sign of the correction is *minus*. When the *drift* is left, correct to the *right*, and the sign of the correction is *plus*.

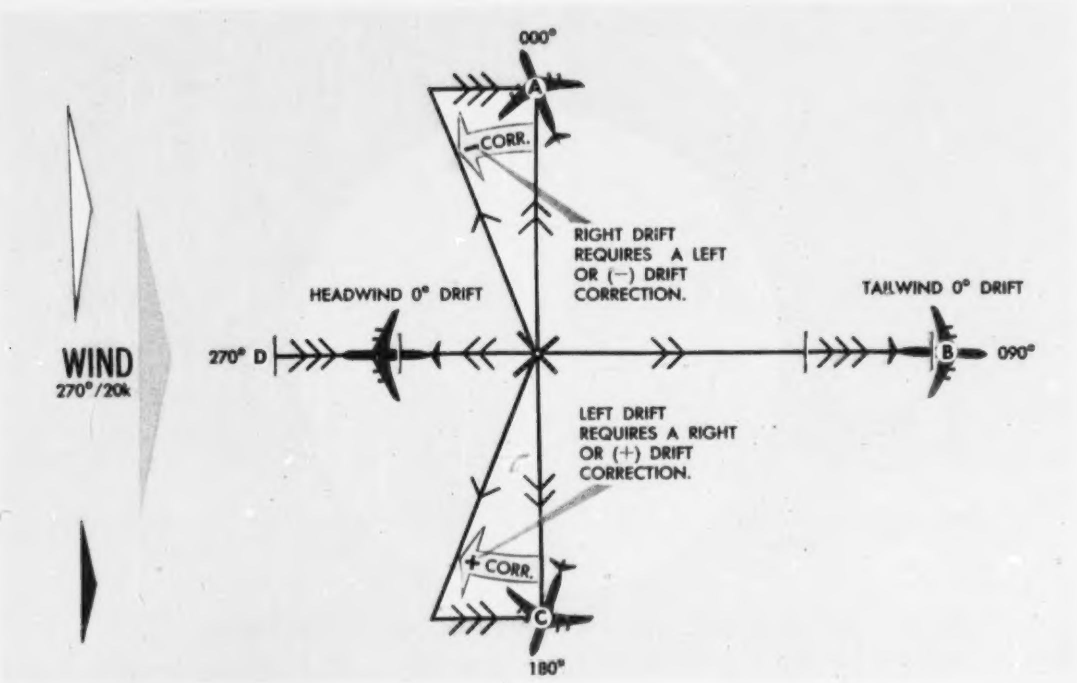

000°
A
− CORR.
RIGHT DRIFT REQUIRES A LEFT OR (−) DRIFT CORRECTION.
HEADWIND 0° DRIFT
TAILWIND 0° DRIFT
WIND
270°/20k
270° D
B
090°
LEFT DRIFT REQUIRES A RIGHT OR (+) DRIFT CORRECTION.
+ CORR.
C
180°

Figure 5-31. Maintaining Course in Wind

Keep in mind a mental picture of the compass rose and how directions increase clockwise.

Remember that after compensation for drift, the aircraft will still drift. All that has been done is to head the aircraft off course so that the wind will cause it to drift along the course while maintaining a constant heading. This correction in the heading of the aircraft cannot, of course, have any effect on the wind. The wind is a natural element over which there is no control.

Vectors and Vector Diagrams

In aerial navigation there are many problems to solve involving speeds and directions. These speeds and directions fit together in pairs, one speed with one direction. Previously it was stated that wind should be expressed as a direction and as a speed, never as a direction or a speed alone. Of the other factors involving speed and direction, true heading (a direction) is related to true airspeed (a speed), and track (a direction) is related to groundspeed (a speed). These last four can be expressed separately and solved separately.

It has been shown how wind is expressed as a force with direction and speed horizontal to the earth's surface. This force affects the movement of aircraft much the same as the current of a river affects a boat. It has also been pointed out that by turning an aircraft into the wind, it is possible to correct for the wind effect. A more exact method of determining wind effect and a correction for it are needed. By using vector solution methods, unknown quantities can be found. For example, true heading, true airspeed, and wind velocity may be known, and track and groundspeed unknown. To solve such problems, the relationships of these quantities must be understood.

The vector can be represented on paper by a straight line. The direction of this line would be its angle measured clockwise from true north, while the magnitude or speed is the length of the line compared to some arbitrary scale. An arrow-head is drawn on the line representing a vector to avoid any misunderstanding of its direction. This line drawn on paper to represent a

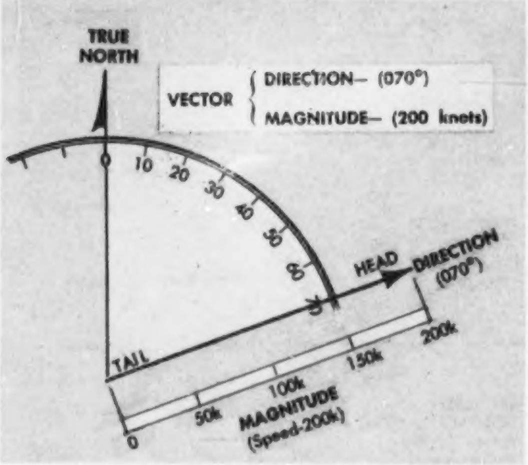

TRUE NORTH
VECTOR
DIRECTION— (070°)
MAGNITUDE— (200 knots)
10
20
30
40
50
60
70
HEAD
DIRECTION (070°)
TAIL
0
50k
100k
150k
200k
MAGNITUDE (Speed-200k)

Figure 5-32. A Vector Has Both Magnitude and Direction

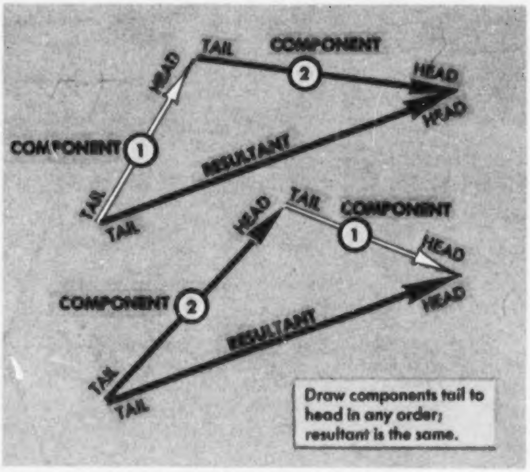

TAIL
COMPONENT
2
HEAD
HEAD
COMPONENT
1
RESULTANT
HEAD
TAIL
TAIL
HEAD
TAIL
COMPONENT
1
HEAD
COMPONENT
2
RESULTANT
HEAD
TAIL
TAIL
Draw components tail to head in any order; resultant is the same.

Figure 5-33. Resultant Vector Is Sum of Component Vectors

vector is known as a vector diagram, or often it is referred to simply as a *vector* as shown in figure 5-32. Future references to the word vector will mean its graphic representation.

Two or more vectors can be added together simply by placing the tail of each succeeding vector at the head of the previous vector. These vectors added together are known as *component vectors.* The sum of the component vectors can be determined by connecting, with a straight line, the tail of one vector to the head of the other. This sum is known as the *resultant vector.* By its construction, the resultant vector forms a closed figure as shown in figure 5-33. Notice the resultant is the same regardless of the order as long as the tail of one vector is connected to the head of the other.

The points to remember about vectors are as follows:

- A vector possesses both direction and magnitude.
- In aerial navigation the vectors which we use have speed and direction.
- When the components are represented *tail* to *head* in any order, a line connecting the tail of the first and the head of the last represents the resultant.
- All component vectors must be drawn to the same scale.

Wind Triangle and Its Solution

A vector illustration showing the effect of the wind on the flight of an aircraft is called a wind triangle. Draw a line to show the direction and speed of the aircraft through an air mass (TH and TAS); this vector is called the TH-TAS vector or *air vector.* Using the same scale, connect the tail of the wind vector to the head of the air vector. Draw a line to show the direction and speed of the wind (W/V); this is the *wind vector.* A line connecting the tail of the air vector with the head of the wind vector is the resultant of these two component vectors; it shows the direction and speed of the aircraft over the earth (Tr and GS). It is called the Tr-GS vector or *ground vector.* It makes little difference which of the two components is drawn first; the resultant is the same.

To distinguish one from another, it is necessary to mark each vector. Accomplish this by placing *one* arrowhead at midpoint on the air vector pointing in the direction of true heading. The ground vector has *two* arrowheads at midpoint in the direction of track. The wind vector is labeled with *three* arrowheads in the direction the wind is blowing. The completed wind triangle is shown in figure 5-34.

Remember that wind direction and wind speed compose the wind vector. True airspeed is always in the direction of true heading; when these two are used together they form the air vector. Similarly, groundspeed is always in the direction of track; these two make up the ground vector when used together.

Also remember that the ground vector is the resultant of the other two; hence, the air vector and the wind vector are always drawn *head* to *tail*. An easy way to remember this is that the wind always blows the aircraft from true heading to track.

Consider just what the wind triangle shows. In figure 5-35, an aircraft departs from point *A* on the true heading of 360° at a true airspeed of 150 knots. In one hour, if there is no wind, it reaches point *B* at a distance of 150 nautical miles. The line *AB* shows the direction and distance the aircraft has flown. But the distance the aircraft has flown in one hour is an expression of its speed (150 nautical miles per hour). Therefore, the length of *AB* shows the true airspeed of the aircraft. Thus *AB* represents the velocity of the aircraft through the air and is the air vector.

Suppose that at the end of the first hour the aircraft stops flying forward and remains suspended in midair. Suppose then that the wind starts blowing from 270° at 30 knots. At the end of the second hour the aircraft is at point *C*, 30 nautical miles downwind, the distance the aircraft has moved with wind, or the direction and distance the air has moved in an hour. Therefore, the length *BC* represents the speed of the wind drawn to the same scale as the true airspeed. Thus, *BC* represents the wind and is the wind vector.

If the aircraft engine and the wind get in their hour's work during the same hour—and that is what actually happens—the aircraft reaches *C* at the end of the first hour. It does not go to *B* and then to *C;* it goes directly by the line *AC* since the wind carries it east at 30 knots at the same time that it moves north at 150 knots. Therefore, the line *AC* shows the distance and direction the aircraft travels over the ground in one hour. Consequently, the length of *AC* represents the groundspeed drawn to the same scale as the true airspeed and wind speed. Thus, the line *AC*, which is the resultant of *AB* and *BC*, represents the motion of the aircraft over the ground and is the ground vector.

Measuring the length of *AC* determines that the groundspeed is 153 knots. Measuring the drift angle, *BAC*, and applying it to the true heading of 360°, results in the track of 011°.

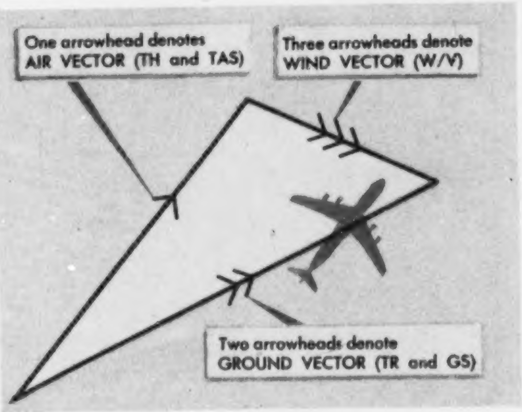


Figure 5-34. Mark Each Vector of Wind Triangle

If two vectors in a wind triangle are known, the third one can be found by drawing a diagram and measuring the parts. Actually, the wind triangle includes six quantities: three speeds and three directions. Problems involving these six quantities make up a large part of dead reckoning navigation. If four of these quantities are known,

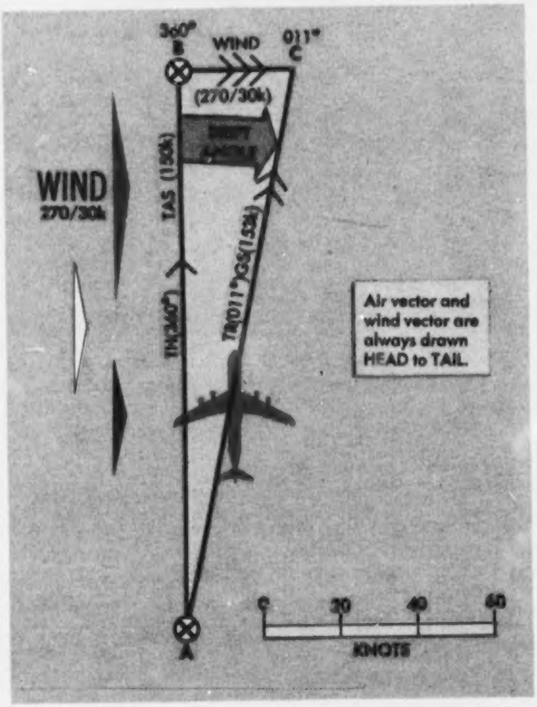


Figure 5-35. Wind Triangle

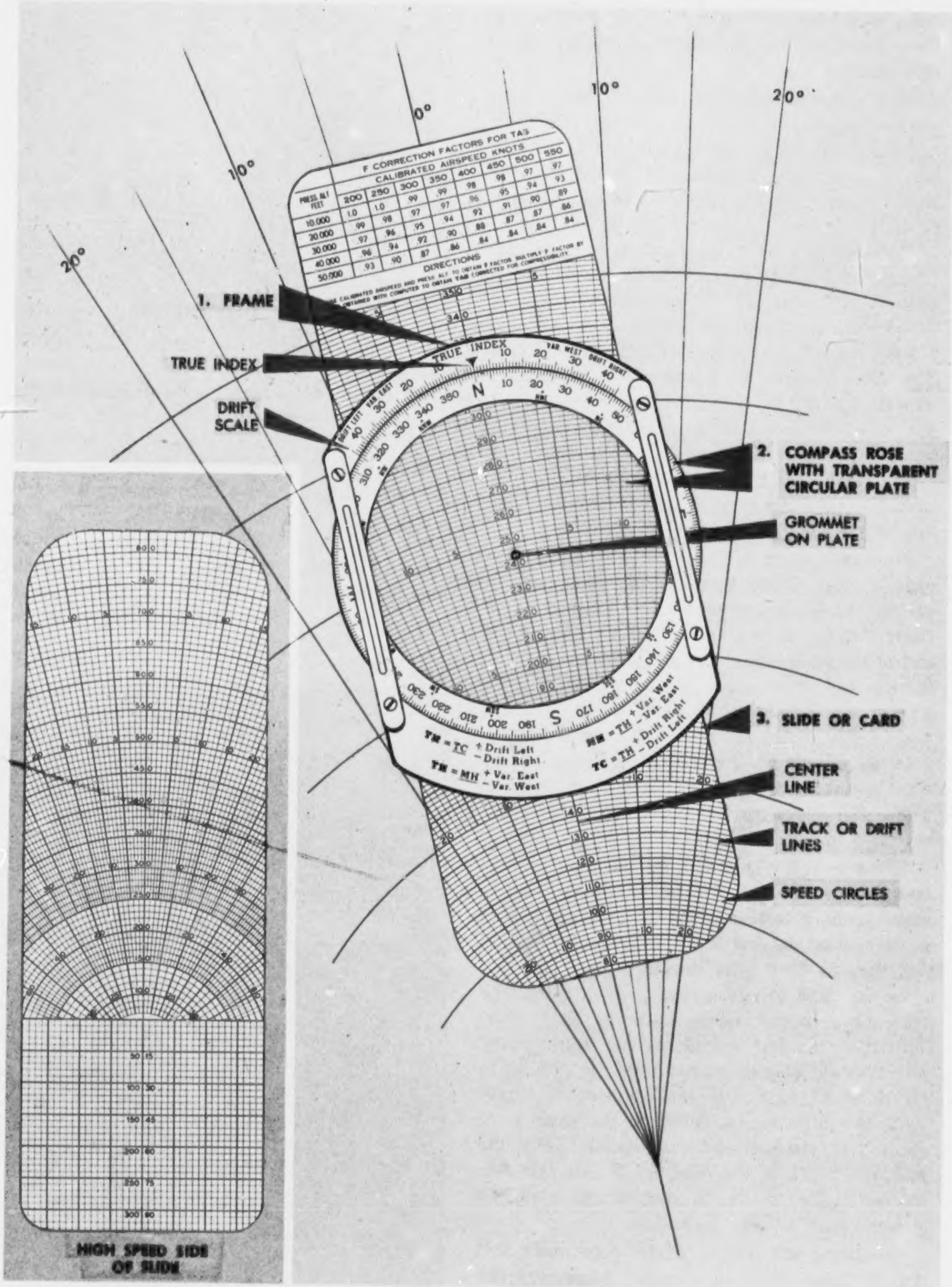

1. FRAME
TRUE INDEX
DRIFT SCALE
2. COMPASS ROSE WITH TRANSPARENT CIRCULAR PLATE
GROMMET ON PLATE
3. SLIDE OR CARD
CENTER LINE
TRACK OR DRIFT LINES
SPEED CIRCLES
HIGH SPEED SIDE OF SLIDE
F CORRECTION FACTORS FOR TAS
CALIBRATED AIRSPEED KNOTS
DIRECTIONS
TRUE INDEX
VAR WEST
DRIFT RIGHT
DRIFT LEFT
VAR EAST
N
S
TH = TC + Drift Left − Drift Right
TH = MH + Var. East − Var. West
MH = TH + Var West − Var. East
TC = TH + Drift Right − Drift Left
0°
10°
20°

Figure 5-36. Wind Face of DR Computer

the other two can be found. This is called solving the wind triangle and is an important part of navigation.

The wind triangle may be solved by trigonometric tables; however this is unnecessary since the accuracy of this method far exceeds the accuracy of the data available and of the results needed. In flight the wind triangle is solved graphically, either on the chart or on the vector or wind face of the computer.

The two graphic solutions of the wind triangle, the chart solution and computer solution, perhaps appear dissimilar at first glance. However, they work on exactly the same principles. Plotting the wind triangle on paper has been discussed; now the same triangle is plotted on the wind face of the computer.

Wind Triangles on DR Computer. The wind face of the computer has three parts: (1) a *frame*, (2) a transparent circular *plate* which rotates in the frame, and (3) a *slide* or *card* which can be moved up and down in the frame under the circular plate. This portion of the computer is illustrated in figure 5-36.

The frame has a reference mark called the TRUE INDEX. A drift scale is graduated 45 degrees to the left and 45 degrees to the right of the true index; to the left this is marked DRIFT LEFT, and to the right, DRIFT RIGHT.

The circular plate has around its edge a compass rose graduated in units of one degree. The position of the plate may be read on the compass rose opposite the true index. Except for the edge, the circular plate is transparent, so that the slide can be seen through it. Pencil marks can be made on the transparent surface. The center of the circular plate is marked by a small black circle called the *grommet*.

The slide has a portion of a circular graph printed on it. Running the length of the slide is a center line, which falls beneath the true index and the grommet. The center line is cut at intervals of two units by arcs of concentric circles called *speed circles;* these are numbered at intervals of 10 units.

On each side of the center line are *track lines,* which radiate from a point of origin off the slide as shown in figure 5-37. Thus the 14° track line on each side of the center line makes an angle of 14° with the center line at the origin. And the point where the 14° track line intersects the speed circle marked 160 is 160 units from the origin.

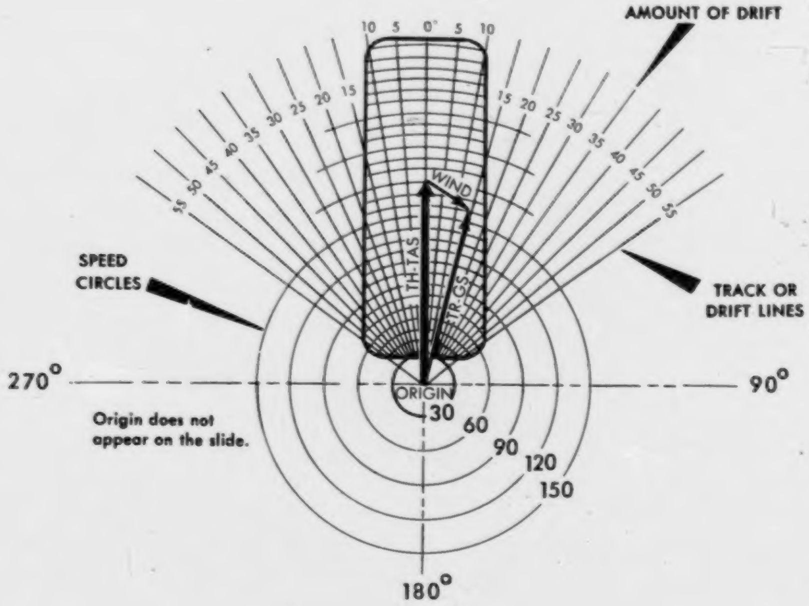
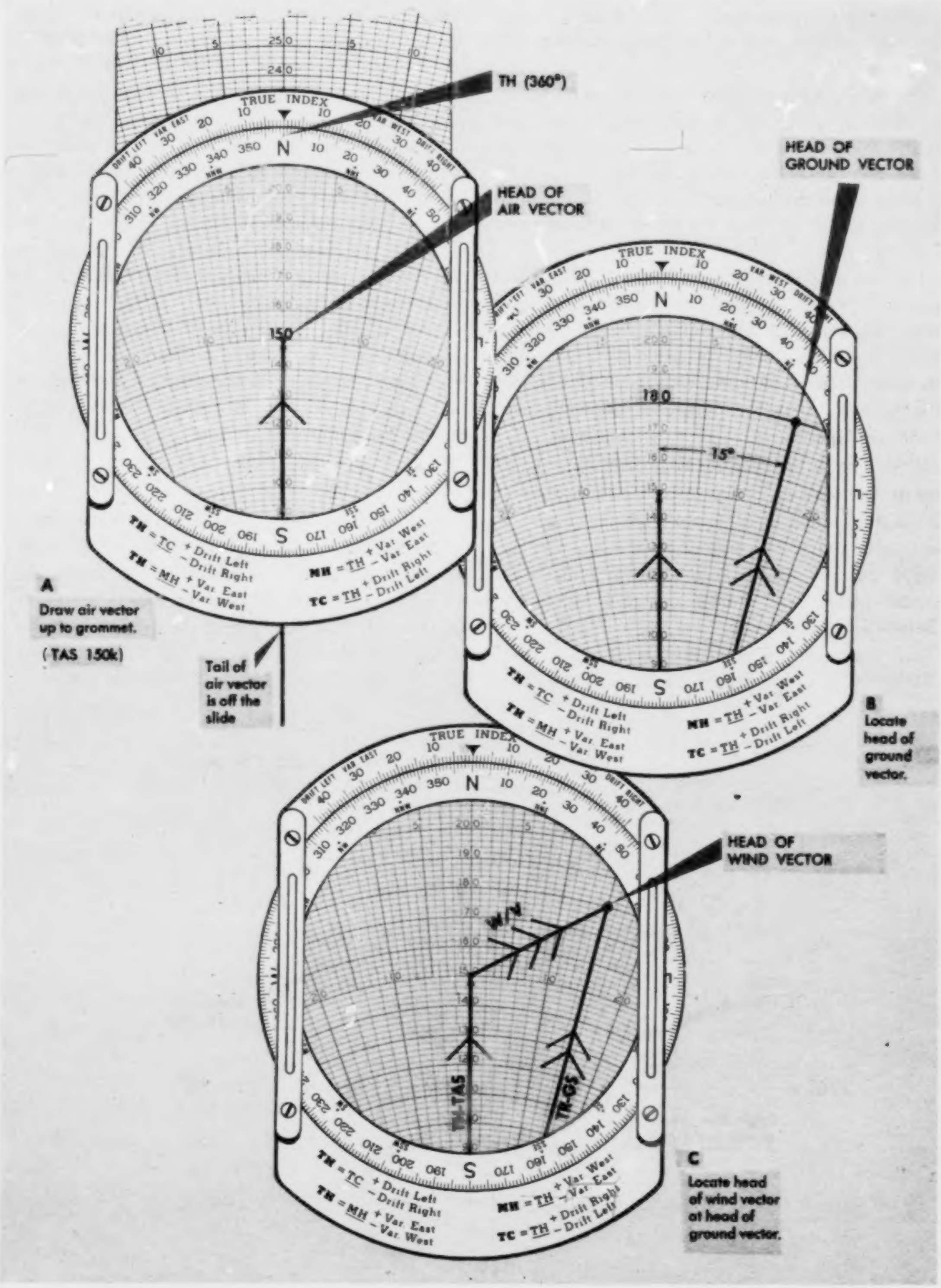


Figure 5-37. Speed Circles and Track Lines



TH (360°)
HEAD OF AIR VECTOR
HEAD OF GROUND VECTOR
HEAD OF WIND VECTOR
TRUE INDEX
150
180
15°
W/V
TH-TAS
TR-GS
TH = TC + Drift Left − Drift Right
TH = MH + Var East − Var West
MH = TH + Var West − Var East
TC = TH + Drift Right − Drift Left

A
Draw air vector up to grommet.
(TAS 150k)

Tail of air vector is off the slide

B
Locate head of ground vector.

C
Locate head of wind vector at head of ground vector.

Figure 5-38. Plotting a Wind Triangle on Computer

In solving a wind triangle on the computer, plot part of the triangle on the transparent surface of the circular plate. For the other parts of the triangle, use the lines which are already drawn on the slide. Actually, there isn't room for the whole triangle on the computer, for the origin of the center line is one vertex of the triangle. When learning to use the wind face of the computer, it may help to draw in as much as possible of each triangle.

The center line from its origin to the grommet always represents the *air vector*. If the true airspeed is 150 knots, move the slide so that 150 is under the grommet; then the length of the vector from the origin to the grommet is 150 units as illustrated in figure 5-38A.

The ground vector is represented by one of the track lines, with its tail at the origin and its head at the appropriate speed circle. If the track is 15° to the right of the true heading, and the groundspeed is 180 knots, use the track line 15° to the right of the center line and consider the intersection of this line with the 180 speed circle as the head of the vector as illustrated in figure 5-38B.

The tail of the wind vector is at the grommet and its head is at the head of the ground vector as shown in figure 5-38C.

Thus far nothing has been said about the direction of the vectors. Since the true index is over the center line beyond the head of the air vector, this vector always points toward the index. Therefore, true heading is read on the compass rose opposite the true index.

Since track is true heading with the drift angle applied, the value of track can be found on the scale of the circular plate opposite the drift correction on the drift scale. The wind vector is drawn with its tail at the grommet as shown in figure 5-39. Since wind direction is the direction *from* which the wind blows, it is indicated on the compass rose by the rearward extension of the wind vector. Therefore, the most convenient way to draw the wind vector is to set wind direction under the true index and draw the vector *down* the center line from the grommet; the scale on the center line can then be used to determine the length of the vector.

Conversely, to read a wind already determined, place the head of the wind vector on the center line below the grommet and read wind direction below the true index.

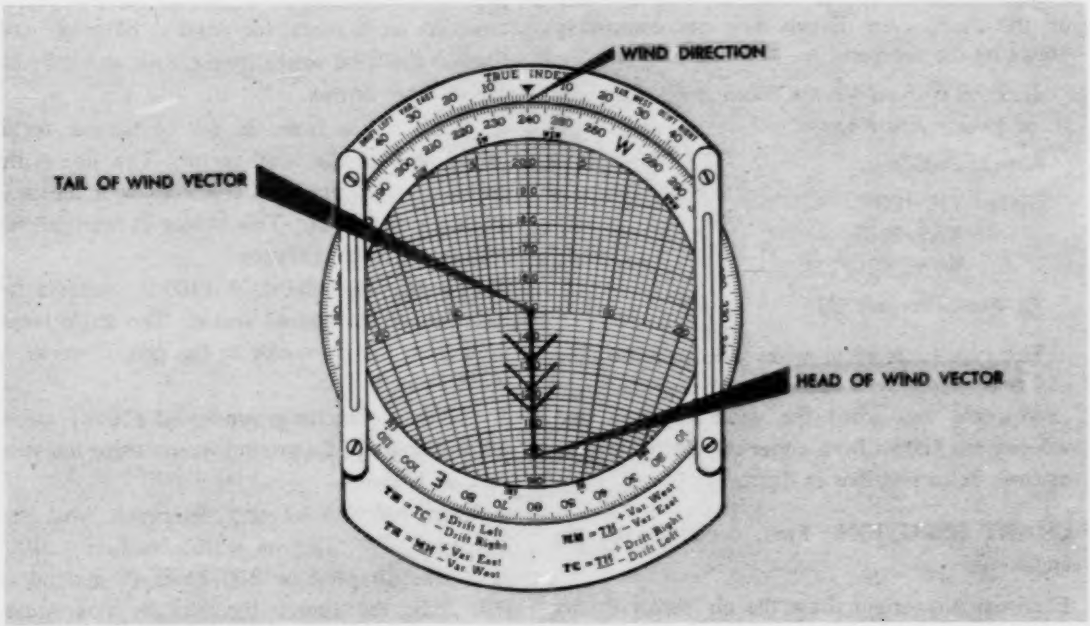

WIND DIRECTION
TRUE INDEX
TAIL OF WIND VECTOR
HEAD OF WIND VECTOR
W
E
TH = TC + Drift Left − Drift Right
TH = MH + Var East − Var West
MH = TH + Var West − Var East
TC = TH + Drift Right − Drift Left

Figure 5-39. Draw Wind Vector Down from Grommet

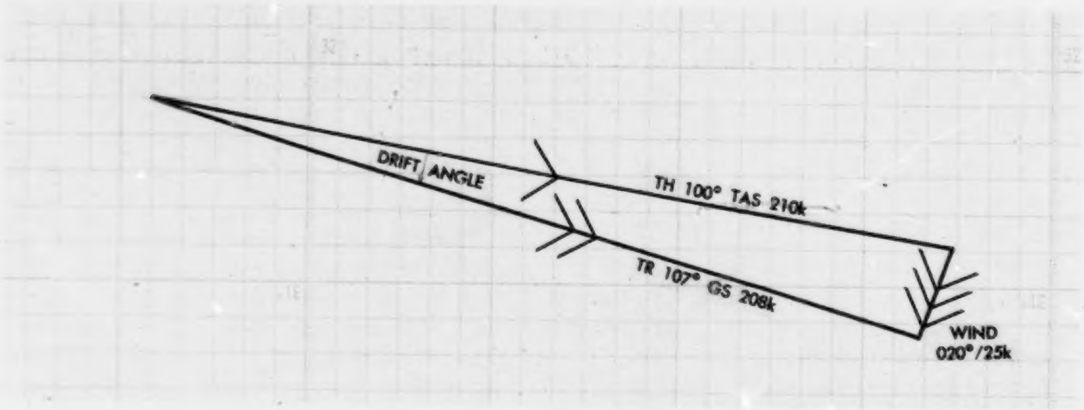


Figure 5-40. To Find Track and Groundspeed Using Chart

WIND TRIANGLE PROBLEMS. Depending on which of the six quantities of the wind triangle are known and which are unknown, there are three principal types of problems to solve. They are to solve for (1) the ground vector, (2) the wind vector, and (3) true heading and groundspeed. The following discussion gives the steps for the chart solution and the computer solution for each type. Work each sample problem by both methods, and notice that the same wind triangle is shown on the computer that is shown on the chart, even though it is not completely drawn on the computer.

To Find Ground Vector When Air Vector and Wind Vector Are Known

Sample Problem:

Given: TH 100°
TAS 210k
W/V, 020/25k

To Find: Tr and GS

This type of problem arises when true heading and true airspeed are known by reading the flight instruments and when the wind direction and velocity are known from either the metro forecast or from determinations in flight.

CHART SOLUTION. First, construct the triangle:

1. From any origin draw the air vector in the direction of the true heading (100°) and to the length representing the true airspeed (210k) in any convenient scale as shown in figure 5-40. When plotting on a Mercator chart, use the midlatitude scale. Mark the air vector with one arrow to indicate the direction, and to be able to identify it as the air vector.

2. From the head of the air vector, draw the wind vector in the direction *toward* which the wind is blowing and to the length showing the wind speed (25k) in the same scale. Remember that the wind direction (020°) is always the direction *from which* the wind is blowing. Distinguish the wind vector from the air vector by the use of three arrows.

3. Draw a line from the tail of the air vector to the head of the wind vector. This line is the ground vector. Its head coincides with the head of the wind vector. This vector is then labeled with two arrows as shown.

4. To determine the track (107°), measure the direction of the ground vector. The angle measured from the air vector to the ground vector is the drift angle.

5. To determine the groundspeed (208k), measure the length of the ground vector, using the same scale as before.

Study figure 5-40 and determine what has happened. By flying on a true heading of 100° at a true airspeed of 210 knots in a wind of 020°/25k, the aircraft has actually moved over the ground along a track of 107° at a groundspeed of 208 knots.

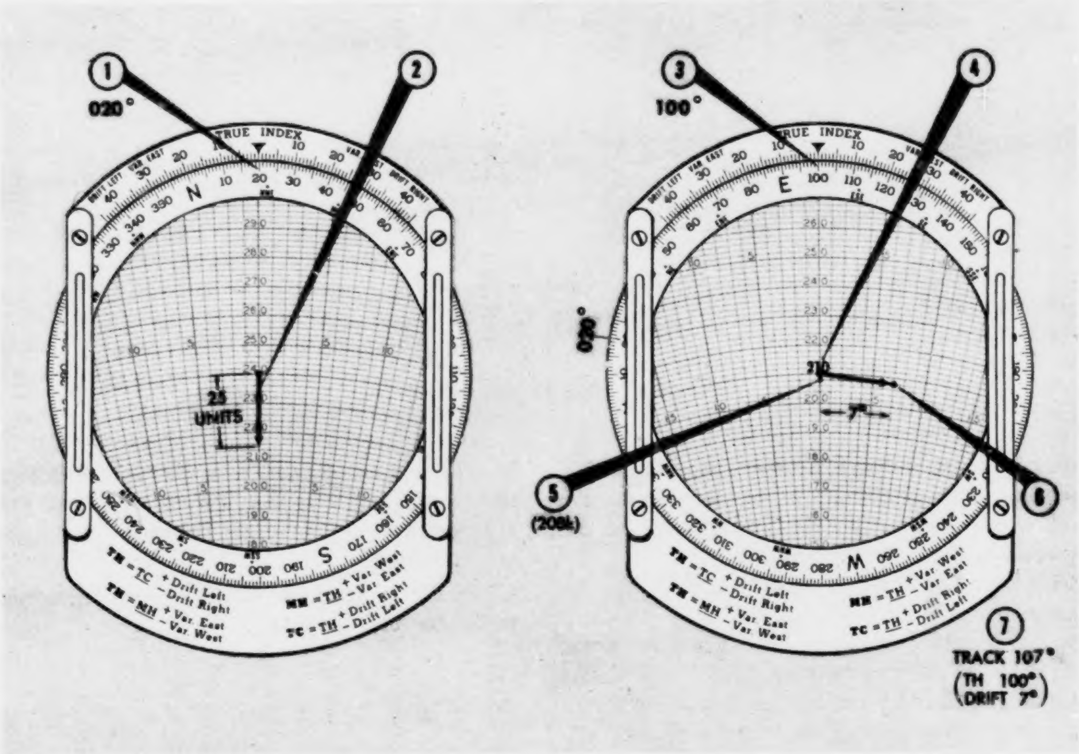


Figure 5-41. To Find Track and Groundspeed Using Computer

COMPUTER SOLUTION: First, set the data:

1. Set wind direction (020°) under the true index.
2. Draw the wind vector from the grommet *down* the center line, making its length (25 units) along the speed scale to conform with the wind speed (25k).
3. By rotating the compass rose, set the true heading (100°) under the true index.
4. Slide the card up or down until the true airspeed (210k) is under the grommet. The wind triangle is now constructed on the computer as illustrated in figure 5-41. The ground vector lies along one of the radiating track (Tr) lines with its head at the head of the wind vector.

Now read the answers.

5. Read groundspeed (208k) on the speed circle which passes through the head of the ground vector.
6. Read the drift angle (7° right) by counting the number of degrees from the center line to the ground vector; that is, to the head of the wind vector.
7. Determine track (107°) by applying the drift angle to the true heading. If the track is right of the center line, it is greater than the true heading; so the drift angle must be added to the true heading. An alternate method of determining track on the computer is to read the drift angle at the head of the ground vector, then transfer this value to the drift scale on the same side of the true index and read the track on the compass rose of the circular disk.

To Find Wind Vector When Air Vector and Ground Vector Are Known

Sample Problem:

Given: TH 270°
Tr 280°
TAS 230k
GS 215k

To Find: W/V

This type of problem arises when determination of true heading and true airspeed can be done by reading the flight instruments and finding track and groundspeed either by measuring the

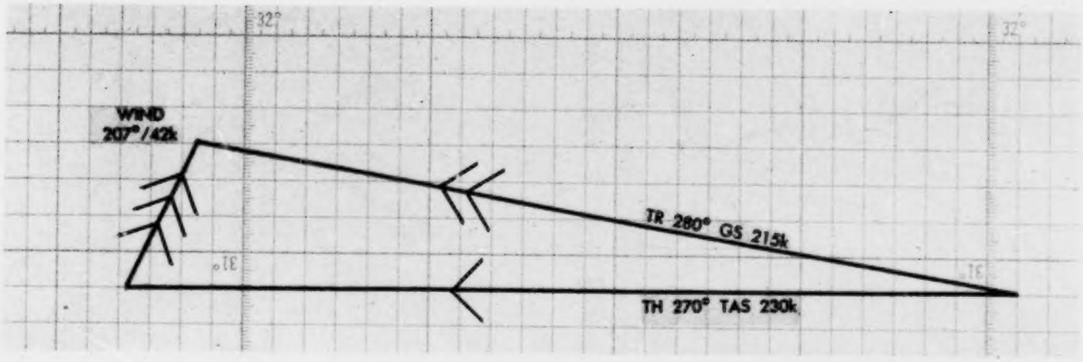


Figure 5-42. To Find Wind Using Chart

direction and distance between two established positions of the aircraft or by determining the drift angle and groundspeed by reference to the ground.

CHART SOLUTION. First, construct the triangle:

1. From any origin draw the air vector in the direction of the true heading (270°) and to the length representing the true airspeed (230k) in any convenient scale as illustrated in figure 5-42.
2. From the same origin, draw the ground vector in the direction of the track (280°) and to the length showing the groundspeed (215k) in the same scale.
3. Draw a line from the head of the air vector to the head of the ground vector. This line is the wind vector. Its head coincides with the head of the ground vector.
4. To determine the wind direction (207°), measure the direction of the wind vector. Remember again that wind direction is the direction from which the wind blows, whereas the vector shows the direction toward which it is blowing. To avoid the possibility of a reciprocal wind direction remember that wind always blows the aircraft from the air vector to the ground vector.
5. To determine wind speed (42k), measure the length of the wind vector, using the same scale as before.

COMPUTER SOLUTION (figure 5-43). First, set in the data:

1. Set the true heading (270°) under the true index.
2. Set the true airspeed (230k) under the grommet.
3. Find the drift angle (10° right) by comparing the true heading (270°) with the track (280°). If the track is greater than the true heading, drift is right; if it is less, drift is left. Find the appropriate track line on the computer (10° right of center line).
4. Find the speed circle (215k) corresponding to the groundspeed circle.

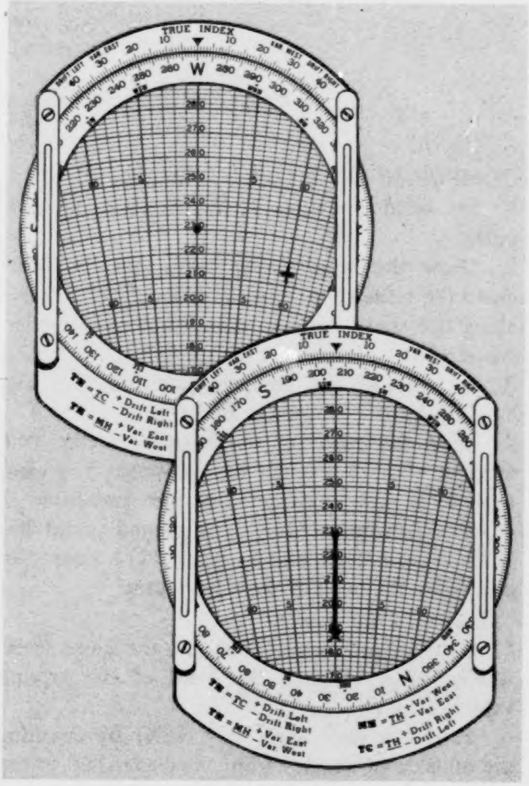

TRUE INDEX
W
TRUE INDEX
S
N
TH = TC + Drift Left − Drift Right
TH = MH + Var East − Var West
MH = TH + Var West − Var East
TC = TH + Drift Right − Drift Left

Figure 5-43. To Find Wind Using Computer

The wind triangle is now constructed. The mark made is the head of the wind vector and the head of the ground vector.

5. Rotate the compass rose until the head of the wind vector is on the center line below the grommet. Read the wind direction (207°) under the true index.

6. Read the wind speed (42k) on the speed scale between the grommet and the head of the wind vector.

To Find True Heading and Groundspeed When True Course, True Airspeed, and Wind Vector Are Known.

Sample Problem:

Given: TC 230°
TAS 220k
W/V 270°/50k

To Find: TH and GS

This type of problem arises before a flight or during a flight, when you need to determine a true heading to fly and groundspeed on the basis of which to compute an ETA.

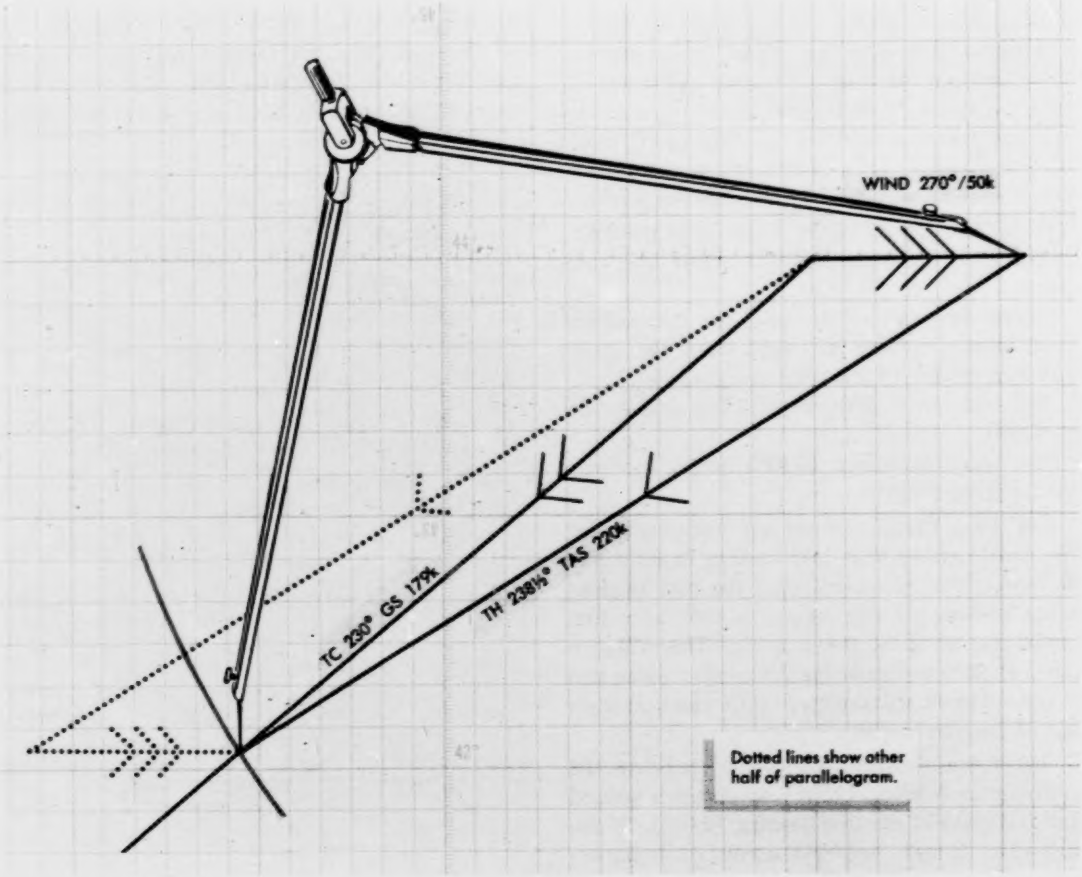
CHART SOLUTION (figure 5-44). First, construct the triangle:

1. From any origin, draw the wind vector in any convenient scale in the direction toward which the wind is blowing (090°) and to the length representing the wind speed (50k).

2. From the same origin, draw a line in the direction of the true course (230°) and of indefinite length, since the groundspeed is not known.

3. Using the same scale as in Step 1, open the dividers an amount equal to true airspeed (220k); from the head of the wind arrow, swing an arc with a radius of 220 nautical miles to intersect the true course line.

4. Draw a line from the point of intersection



Dotted lines show other half of parallelogram.

Figure 5-44. To Find True Heading and Groundspeed Using Chart

of the arc and the true course line to the head of the wind arrow.

5. To determine the true heading (238½°), measure the direction of the air vector.

6. To determine the groundspeed (179k), measure the length of the ground vector, using the same scale as before.

This solution gives a false picture of the vector diagram as previously presented, but it gives true values because it forms the other half of a parallelogram. Notice in figure 5-44 that there is another method of solving this type of problem in which the wind triangle is drawn in its true form.

1. Draw the true course (230°) of indefinite length.
2. Draw the wind vector with its head at any point on the true course.
3. Using the same scale as in Step 1, open the dividers an amount equal to true airspeed. From the tail of the wind vector swing an arc of 220 nautical miles to intersect the true course line.
4. Draw a line from this point of intersection of the arc and the true course line to the tail of the wind vector. Be sure in doing this that the wind and ground vectors are meeting head to head.
5. The answers (TH and GS) can be determined exactly as in Steps 5 and 6 of the previous method.

COMPUTER SOLUTION. First, set in the data:

1. Set wind direction (270°) under the true index.
2. Draw the wind vector down the center from the grommet, making its length along the speed scale correspond to the wind speed (50k).
3. Set the true airspeed (220k) under the grommet.
4. Set the true course (230°) under the true index (figure 5-45).

The wind triangle is set up incorrectly, for true course rather than true heading is set under the true index. However, since the true heading is not known, the true course is used as a first approximation of the true heading. This will give a first approximation of the drift angle, which can be applied to the true course to get a more accurate idea of the true heading.

5. Determine the drift angle (10° left) on the approximate heading (230°) to obtain a second approximation of the true heading (240°). If the drift angle is right, the drift correction is minus; if it is left, the drift correction is plus.
6. Set the second approximate heading (240°) under the true index. Read the drift angle for this heading (8° left). The wind triangle still is set up incorrectly. To be correct, the drift angle which is read at the head of the wind vector must equal the difference between the true course and the true heading which is set under the true index. As it stands, the drift angle is 8° left, while the difference between true course and the indicated true heading is 10° left.
7. Juggle the compass rose until the drift angle equals the difference between true course and true heading. In this example the correct drift angle is 8½° left.

Now the wind triangle is set up correctly.

8. Read the true heading (238½°) under the true index.
9. Read the groundspeed (179k) on the speed circle passing through the head of the wind vector.

High Speed Wind Solutions. When wind speeds too large for the DR computer are encountered, it creates a minor problem. However, note how the linear values of all vectors in a triangle can be changed an equal amount without changing the angles. Or, the scale of the linear values can be changed (each unit on the scale can equal

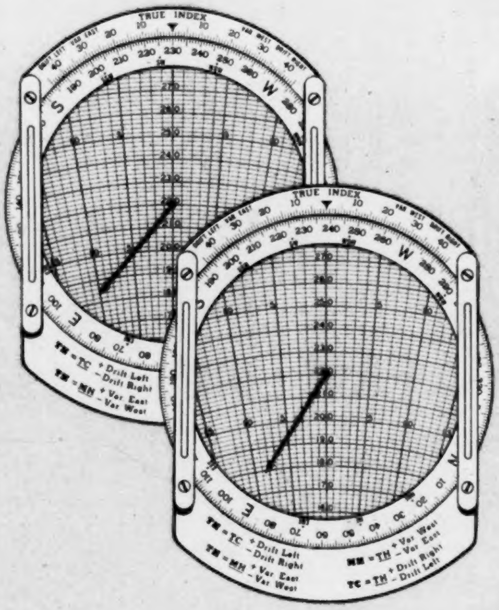

TRUE INDEX
TRUE INDEX
TH = TC + Drift Left − Drift Right
TH = MH + Var East − Var West
MH = TH + Var West − Var East
TC = TH + Drift Right − Drift Left

Figure 5-45. To Find True Heading and Groundspeed Using Computer

two units of the problem) and thus the smaller triangle can represent the same values as the larger triangle. The latter is done on the DR computer. Solve this problem for true heading and groundspeed.

Sample Problem:
Given: TC 250°
TAS 240k
W/V 200°/70k
To Find: TH and GS

1. Place the wind direction (200°) under the true index and draw the wind speed down from the grommet 35 units. Since each unit now represents two knots, this would be 70 knots.
2. Place the grommet over the true airspeed (120k), remembering that each unit represents two knots.
3. Rotate the compass rose until the true course (250°) is under the true index.
4. As in the previous problem, juggle the compass rose until the drift correction angle equals the difference between true course and the true heading. In this example the drift correction angle is minus 13°.
5. Read the true heading under the true index (237°).
6. Read the groundspeed under the head of the wind arrow but remember that the reading must be doubled to compensate for halving the scale of the computer when drawing in the vectors. Ninety-five (95) doubled would give a groundspeed of 190k. By now it should be very clear that changing the linear values or scale of the vectors does not change the angles or directions (this is shown graphically in figure 5-46). Therefore, directions and angles may be read directly from the computer.

Average Wind Affecting Aircraft

An average wind is an imaginary wind which would produce the same wind effect during a given period as two or more actual winds which affect the aircraft during that period. Sometimes an average wind can be applied once instead of applying each individual wind separately. Average wind, like any wind has direction, and its speed is expressed in knots. Normally, average wind is the average wind effect for one hour.

If the wind directions are fairly close together, a satisfactory average wind can be determined by arithmetically averaging the wind directions and wind speeds. However, the greater the variation in wind direction the less accurate the result will be.

It is generally accepted that winds should not be averaged arithmetically if the difference in directions and speeds exceeds 090° and/or 15 knots. In this case, there are other methods which may be used to obtain a more accurate average wind.

CHART SOLUTION: Find the sum of the several wind vectors by drawing them tail to head and connecting the tail of the first with the head of the last. This, then, is the wind effect for as many hours as there are wind vectors. The direction of the average wind is the direction of this resultant. The speed of the average wind is the wind effect divided by the number of hours; that is, by the number of winds averaged.

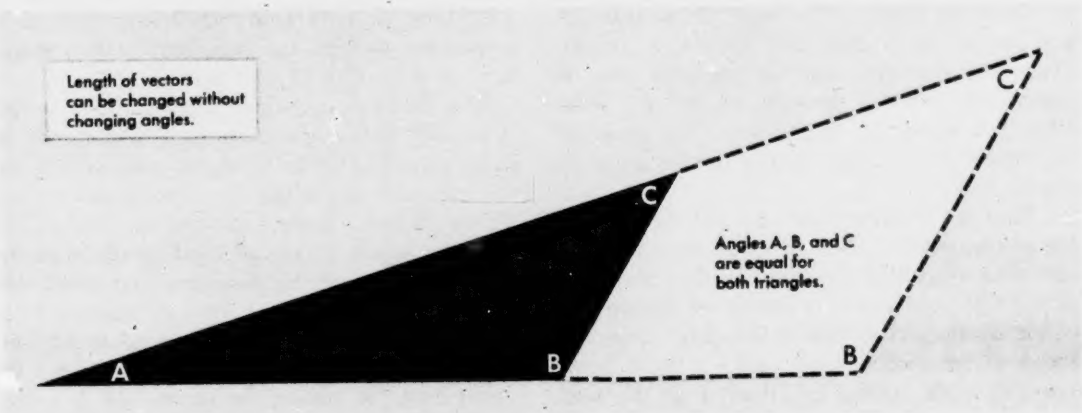
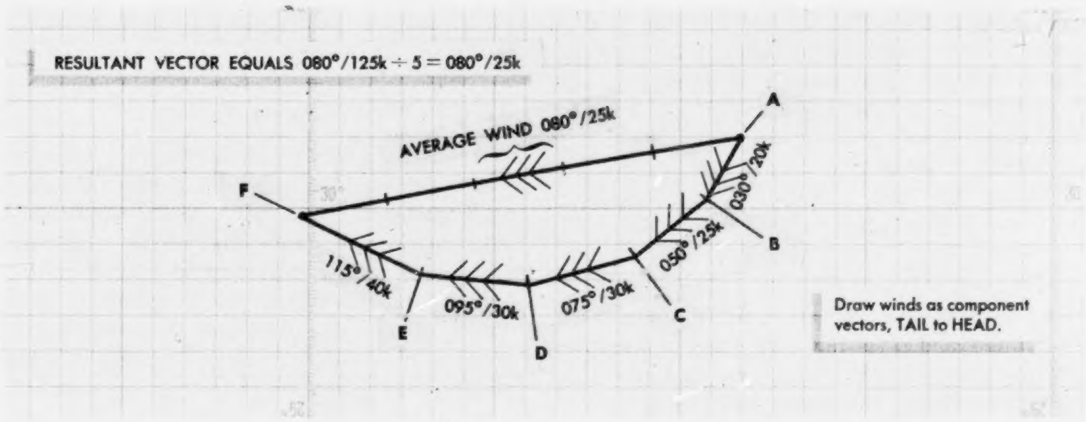

Length of vectors can be changed without changing angles.
C
C
Angles A, B, and C are equal for both triangles.
A
B
B

Figure 5-46. Angles and Directions Do Not Change


RESULTANT VECTOR EQUALS 080°/125k ÷ 5 = 080°/25k

Draw winds as component vectors, TAIL to HEAD.

Figure 5-47. To Find Average Wind Using Chart

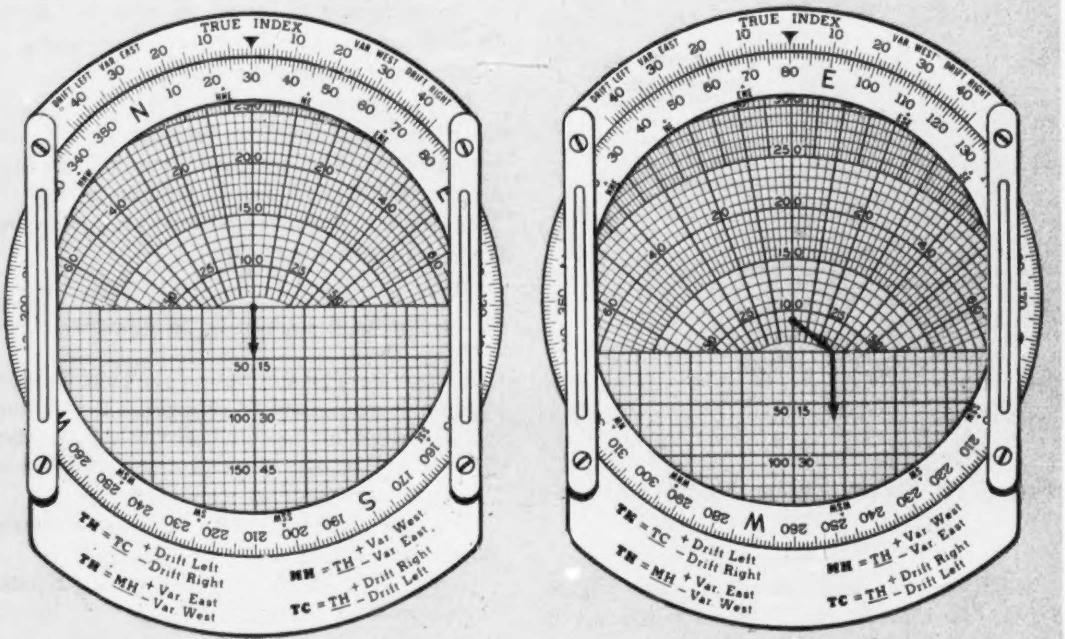
To average the following five winds: (A) 030°/20k, (B) 050°/25k, (C) 075°/30k, (D) 095°/30k, and (E) 115°40k, represent the winds as component vectors *AB, BC, CD, DE, EF,* and draw them in turn, tail to head as shown in figure 5-47. Then draw the resultant, *AF*.

The direction of the average wind is the direction of line *AF*, 080°. The length of *AF* represents a wind effect of 125 nautical miles for a period of 5 hours. Therefore, the speed of the average wind is 125 nautical miles per 5 hours or 25k.

COMPUTER SOLUTION: Winds can also be averaged by vectoring them on the wind face of the DR computer using the square grid portion of the slide and the rotatable compass rose. Average the following three winds by this method—030°/15k, 080°/20k, and 150°/35k:

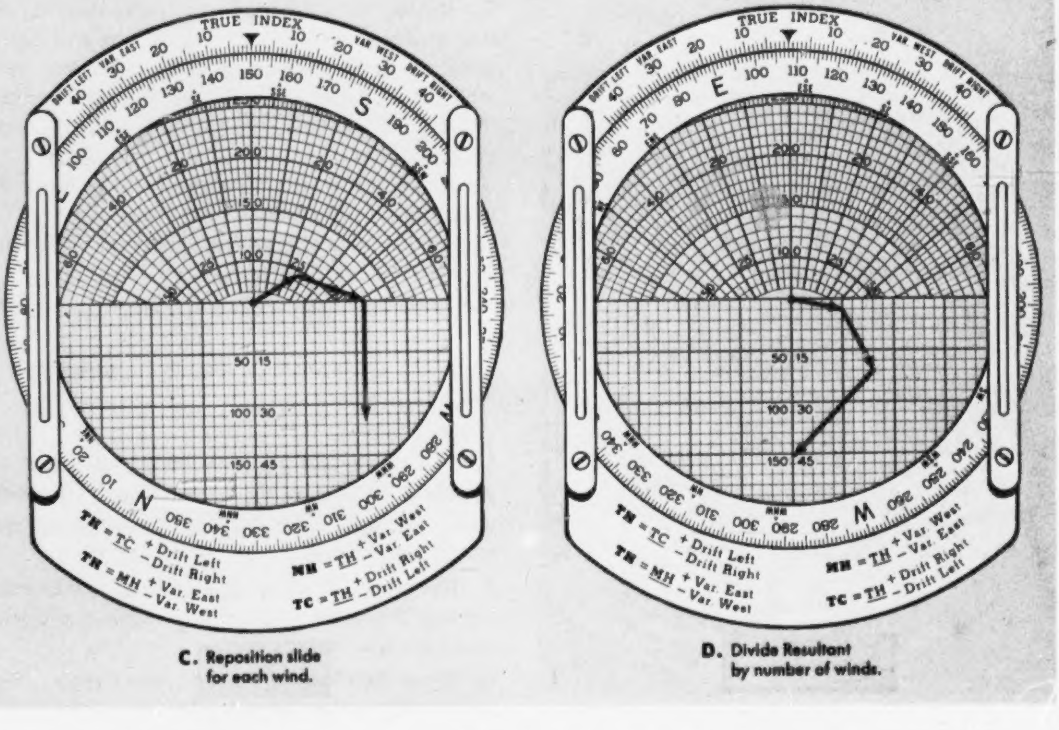
1. Place the slide in the computer so that the top line of the square grid portion is directly under the grommet and the compass rose is oriented so that the direction of the first wind (030°) is under the true index. The speed of the wind (15k) is drawn down from the grommet (figure 5-48A).
2. Turn the compass rose until the direction of the second wind (080°) is under the true index and then reposition the slide so that the head of the first wind vector is resting on the top line of the square grid section of the slide. Draw the speed of the second wind (20k) straight down (parallel to the vertical grid lines) from the head of the first wind arrow (figure 5-48B).
3. Again turn the compass rose so that the direction of the third wind (150°) is under the true index and reposition the slide so that the head of the second wind vector is resting on the top line of the square grid section of the slide. Draw the speed of the third wind (35k) straight down from the head of the second wind arrow (figure 5-48C).
4. Turn the compass rose so that the head of the third wind arrow is on the center line directly below the grommet and reposition the slide to place the grommet on the top line of the square grid section of the slide. The direction of the resultant or average wind may be read directly beneath the true index (108°). The wind speed is determined by measuring the length of the resultant wind vector (46) on the square grid section of the slide and dividing it by the number of winds used (3). This will give a wind speed of 15⅓ knots or 15½ knots which is as close as it is possible to read the computer. The average wind then is 108°/15½k (figure 5-48D).

In some cases because of the number of winds to be averaged or because of high wind speeds, it is not possible to draw in all the wind vectors on the computer unless the wind speeds are cut by ½ or ⅓, etc., before drawing the vector. If one wind speed is cut, all wind speeds must be cut. In determining the resultant wind speed, the length of the total vector must be multiplied by 2 or 3, depending on how the wind speed was cut, and then divided by the total number of winds used. In cutting the speeds, the direction is not affected and the wind direction is read under the true index.


TRUE INDEX
DRIFT LEFT
VAR EAST
VAR WEST
DRIFT RIGHT
N
E
S
W
E
TH = TC + Drift Left − Drift Right
TH = MH + Var. East − Var West
MH = TH + Var. West − Var. East
TC = TH + Drift Right − Drift Left

A. First wind is drawn down from the grommet.

B. Reposition slide and draw down again.


TRUE INDEX
DRIFT LEFT
VAR EAST
VAR WEST
DRIFT RIGHT
S
N
E
W
TH = TC + Drift Left − Drift Right
TH = MH + Var. East − Var West
MH = TH + Var. West − Var. East
TC = TH + Drift Right − Drift Left

C. Reposition slide for each wind.

D. Divide Resultant by number of winds.

Figure 5-48. To Find Average Wind Using Computer

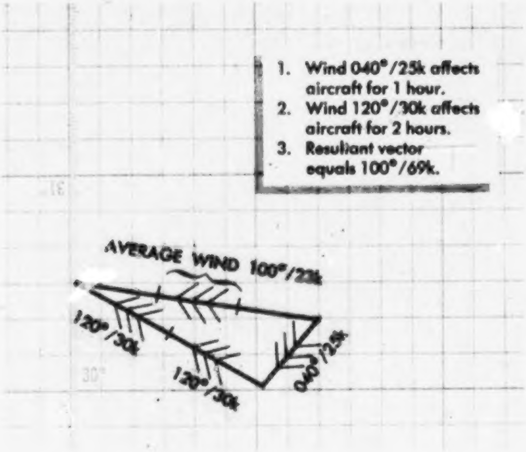

1. Wind 040°/25k affects aircraft for 1 hour.
2. Wind 120°/30k affects aircraft for 2 hours.
3. Resultant vector equals 100°/69k.
AVERAGE WIND 100°/23k
120°/30k
120°/30k
040°/25k

Figure 5-49. Weight Winds in Proportion to Time

Wind effect is proportional to time (figure 5-49). To sum up two or more winds which have affected the aircraft for different lengths of time, weight them in proportion to the times. If one wind has acted twice as long as another, its vector should be drawn in twice as shown. In dividing to get the average wind speed, of course, this wind must be counted twice.

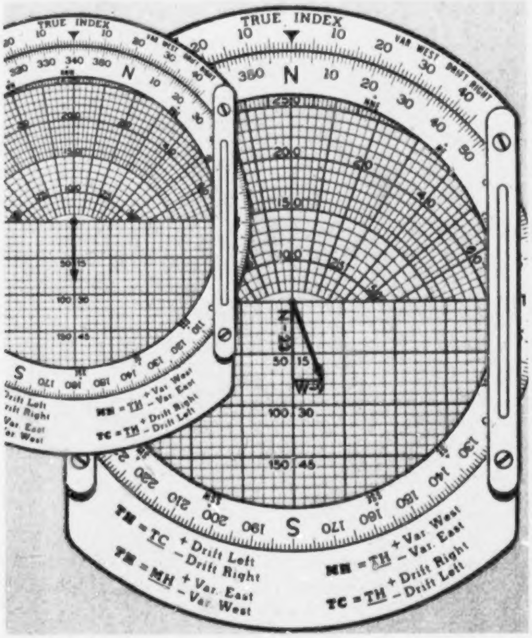

TRUE INDEX
TRUE INDEX
N
S
W
TH = TC + Drift Left − Drift Right
TH = MH + Var. East − Var. West
MH = TH + Var. West − Var. East
TC = TH + Drift Right − Drift Left

Figure 5-50. Convert Wind to Rectangular Coordinates

Throughout the discussion of the wind triangle, the wind vector has been referred to as having both direction and speed. In future discussions of the wind vector, it may be referred to as W/V. This term is commonly used for wind speed when coupled with wind direction.

Resolution of Rectangular Coordinates

Since most data for radar equipment is given in terms of rectangular coordinates, it is important that the navigator be familiar with the handling of these coordinates. The DR computer provides a ready, easy method of interconversion.

Example: Converting wind to rectangular coordinates (figure 5-50).

Given: A wind of 340°/25k to be converted to rectangular coordinates.

Procedure:

1. Plot the wind on the computer in the normal manner. Use the square grid side of the computer slide for the distance.
2. Rotate the compass rose until north, the nearest cardinal heading, is under the true index.
3. Read down the vertical scale to the line upon which the head of the wind vector is now located. The component value (23) is *from* the north under the true index.
4. Read across the horizontal scale from the center line to the head of the wind vector. The component value (9) is from the west. The wind is stated rectangularly as N-23, W-9.

Example: Converting rectangular coordinates to a wind.

Given: Coordinates, S-30, E-36, to convert to a wind.

Procedure:

1. Use the square grid side of the computer.
2. Place either cardinal heading (east or south) under the true index and the grommet on zero of the square grid.
3. Read down from the grommet along the center line for the value (30) of the cardinal direction under the true index.
4. *From* the other cardinal direction (east), read horizontally along the value located in Step three from the center line of the value of the second cardinal direction and mark the point.

5. Rotate the compass rose until the marked point is over the center line of the computer.

6. Read the wind direction (130) under the true index and the velocity (47 knots) from the grommet to the point marked.

DRIFTMETER

By this time the navigator should realize that accurate wind determination is a main source of difficulty in performing his duties. The wind problem is ever present in navigation. If the air were absolutely still, aerial navigation would be very simple. Without wind, the aircraft would not drift off its course. Unfortunately, however, still air seldom, if ever, exists. Therefore, navigation with its costly equipment and detailed procedures is made necessary. The navigator must continually determine the wind or the effect of the wind if he is to obtain the results required for accurate navigation.

Several methods of wind determination depend on the knowledge of the drift angle—the angle between true heading and track. When the earth's surface (land or sea) is visible, this angle can be measured directly with an instrument known as a *driftmeter*.

Principle of the Driftmeter

The principle of the driftmeter is very simple. Suppose that the ground is observed through a hole in the floor of an aircraft. As the aircraft flies along its track, objects on the ground appear to move across the hole in the direction exactly opposite to the track.

Thus, in figure 5-51 if the aircraft track is in the direction of line *BA*, a house appears to move across the hole from *A* to *B*. Suppose now that a wire is stretched across the hole parallel to the longitudinal axis of the aircraft. This wire *YX* represents the true heading of the aircraft. Since *BA* is the track and *YX* is the true heading, the drift angle is the angle *AOX*. The driftmeter measures this angle *AOX*. A simple driftmeter might be built as shown in figure 5-52. A glass plate which may be rotated by means of the handle on the right is placed over a hole in the floor of the aircraft. On the glass are drawn parallel *drift* lines. The drift lines, together with the two or three cross lines (timing lines) usually present in a driftmeter, are called the *reticle*. The center drift line extends to the edge of the plate as a pointer. On the floor ahead of the hole is a drift scale which shows the position of the drift lines relative to the longitudinal axis of the aircraft. Thus when the pointer is on 0°, the

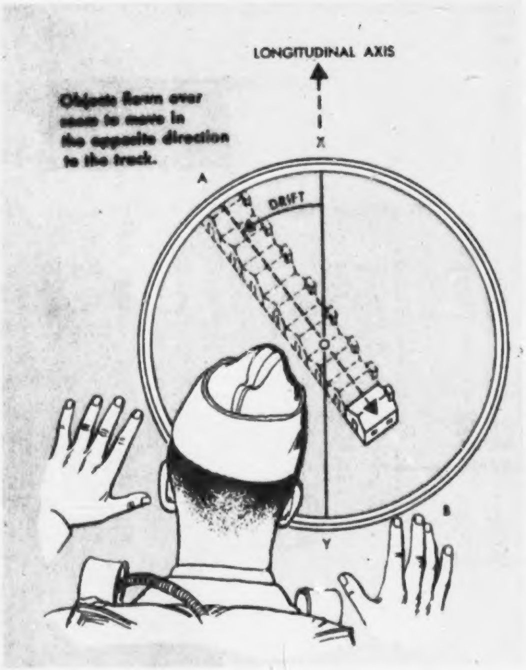

LONGITUDINAL AXIS
Objects flown over seem to move in the opposite direction to the track.
X
A
DRIFT
B
Y

Figure 5-51. Principle of a Driftmeter

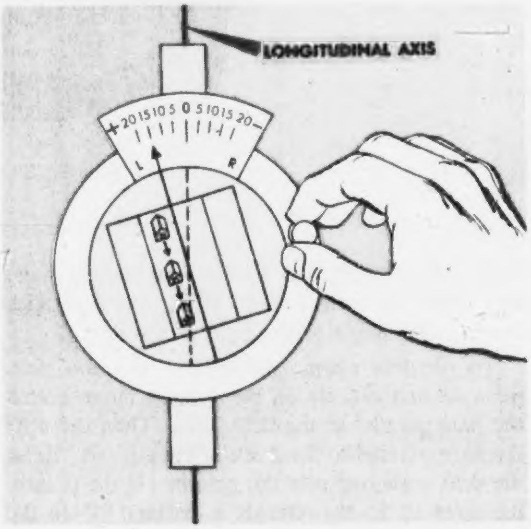


Figure 5-52. Read Drift on Scale Opposite Pointer

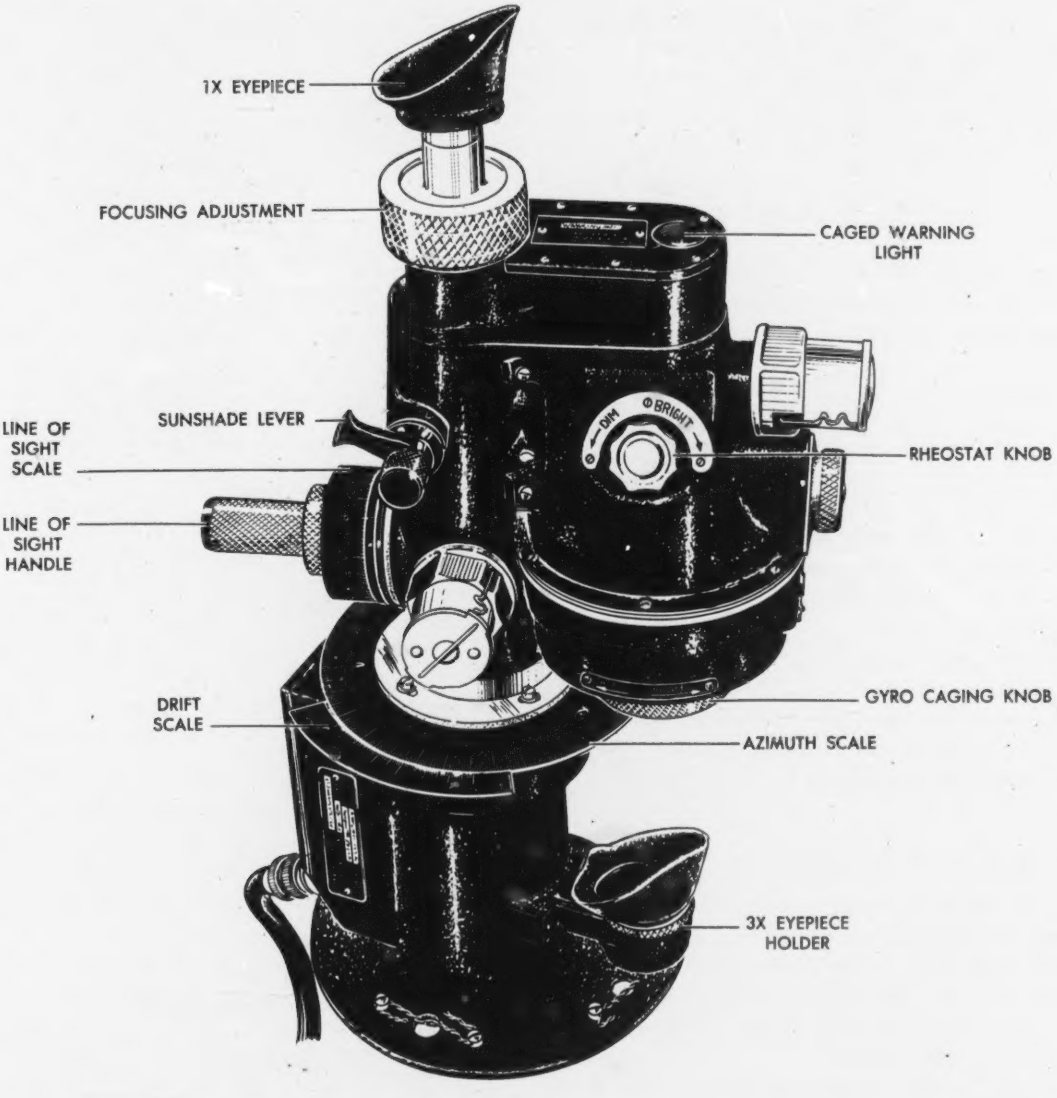

1X EYEPIECE
FOCUSING ADJUSTMENT
CAGED WARNING LIGHT
SUNSHADE LEVER
LINE OF SIGHT SCALE
RHEOSTAT KNOB
DIM
BRIGHT
LINE OF SIGHT HANDLE
GYRO CAGING KNOB
DRIFT SCALE
AZIMUTH SCALE
3X EYEPIECE HOLDER

Figure 5-53. Typical Driftmeter

drift lines are parallel to the longitudinal axis; and when the pointer is on 10°R, the drift lines make a 10° angle to the right of the axis.

To use this simple driftmeter, turn the glass plate so that objects on the ground move across the hole parallel to the drift lines. Then the drift lines are parallel to the track of the aircraft. Read the drift scale opposite the pointer. If the pointer indicates 15°L, the aircraft is drifting 15° to the left. Then if the true heading is 090°, the track is 075°.

On every driftmeter, the drift scale is marked with the words "right" and "left" or with the letters "R" and "L." These words always refer to the *drift* and not to the drift correction. Normally, driftmeters have a plus and a minus sign on the scale. These give the sign of the *drift correction* (DC) which is discussed later.

The typical driftmeter shown in figure 5-53 is basically the same as the simple instrument described above, but it has many refinements. One of the most important refinements is the use of a

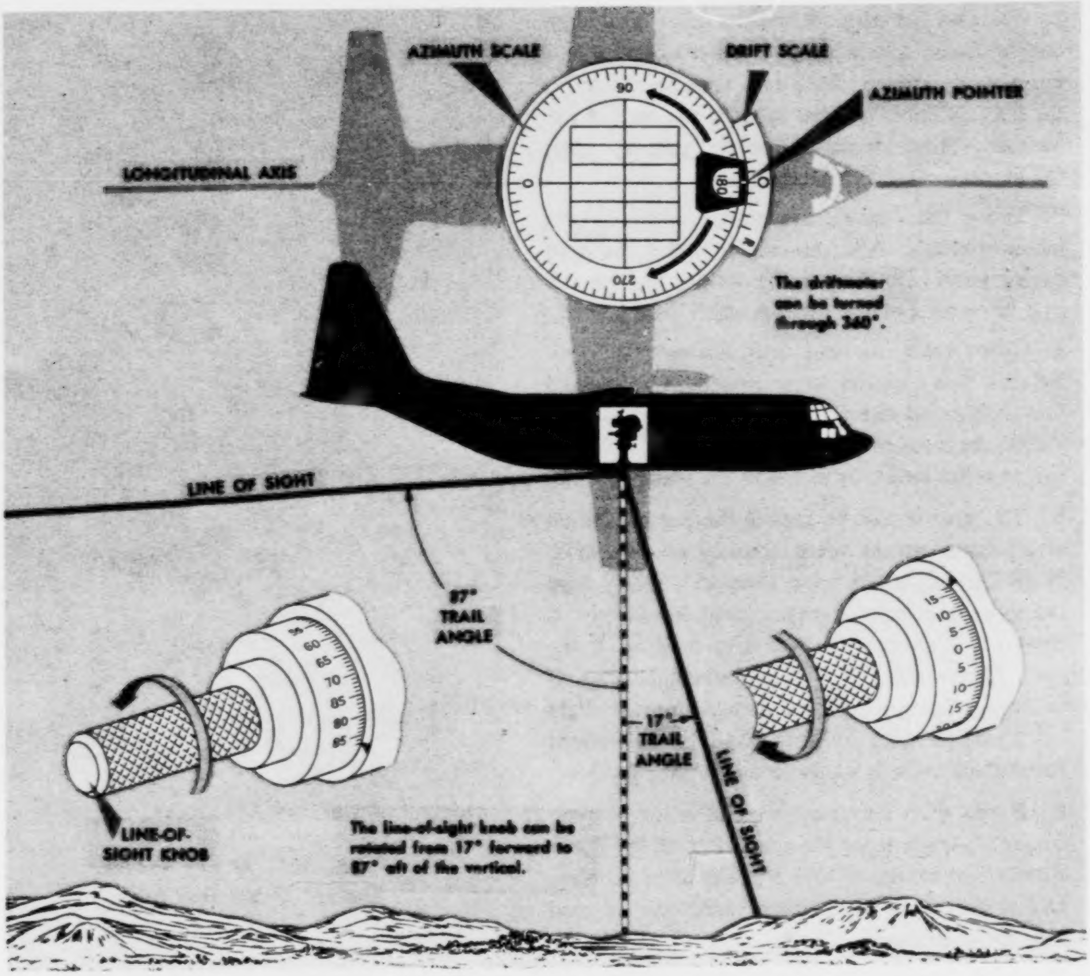

AZIMUTH SCALE
DRIFT SCALE
AZIMUTH POINTER
LONGITUDINAL AXIS
90
0
180
270
L
R
The driftmeter can be turned through 360°.
LINE OF SIGHT
87° TRAIL ANGLE
55
60
65
70
75
80
85
15
10
5
0
5
10
15
17° TRAIL ANGLE
LINE OF SIGHT
LINE-OF-SIGHT KNOB
The line-of-sight knob can be rotated from 17° forward to 87° aft of the vertical.

Figure 5-54. Trail Angle

gyro to keep the reticle horizontal. A driftmeter without a gyro is difficult to use in turbulent air. An azimuth scale has been added to aid the navigator in determining relative bearings of objects. Two eyepieces of varying magnifying power are provided to give the navigator a better view of the ground.

The glass plate has been improved by adding a system of prisms with which the navigator may direct his line of sight away from the vertical by turning the line of sight handle. Figure 5-54 shows that when the azimuth pointer is at 180° on the azimuth scale, the line of sight can be turned through an arc from 17° forward to 87° aft of the vertical. The angle between the line of sight and the vertical is the *trail angle*. Since the driftmeter can be rotated through 360°, a trail angle of 87° can be seen in any direction from the aircraft.

Operation

The driftmeter is a delicate instrument which requires careful treatment. Read the following operating procedure carefully:

1. Before takeoff, clean the lens at the bottom of the driftmeter tube. To remove grit, brush lightly to avoid scratching the glass. Also check the inside of the lens for condensation of moisture in the tube. If present, it may be remedied by removing the lens and wiping with a clean, soft cloth.

2. See that the azimuth pointer is at zero drift during takeoff and landing to prevent breakage of the glass by stones. With zero drift on the scale, the lens system is pointed towards the rear of the aircraft. Thus, stones or gravel flying up from the runway cannot strike the lens.

3. When the engines are started, turn on the inverter switch. After making sure that the gyro caging knob is in the caged position, turn on the gyro by means of the three-position switch.

4. When ready to read drift, uncage the gyro. Be sure that the trail angle control is at zero so that the ground directly below the aircraft is seen. Adjust the focus of the eyepiece. Adjust the illumination of the reticle by means of the rheostat knob.

5. The gyro should be kept in the caged position at all times except when actually reading drift. If the aircraft banks more than 15°, gently cage the gyro and leave it caged until level flight is resumed; otherwise the gyro may tumble. If the gyro does tumble, cage it only when the aircraft is level. Caging a tumbled gyro requires a slight but steady pressure on the caging knob. A sudden forceful pressure is likely to cause damage.

6. If the gyro becomes inoperative or tumbles frequently, cage it for the remainder of the flight. Remember to report the trouble after landing. Unless the air is very rough, drift can be read with the gyro caged.

7. Before landing, cage the gyro, turn off the power switch, and return the azimuth pointer to the zero position of the drift scale.

Reading Drift

Watch the terrain for a time through the driftmeter (at any trail angle setting). Turn the azimuth drive until the drift lines are parallel with the path of each object across the field of vision. Read the drift on the drift scale opposite the azimuth pointer.

After reading drift, turn the pointer several degrees away from the drift reading. Then when drift is read again, it will be an independent reading and not influenced by the previous reading.

Above 2,000 feet, good drift readings can be obtained on objects directly beneath the aircraft; at low altitudes, however, objects may pass by too rapidly for accurate readings. This difficulty can be overcome by using other methods of reading drift. One of these methods is to set the trail angle back to 25° or 50° and read drift in the normal manner.

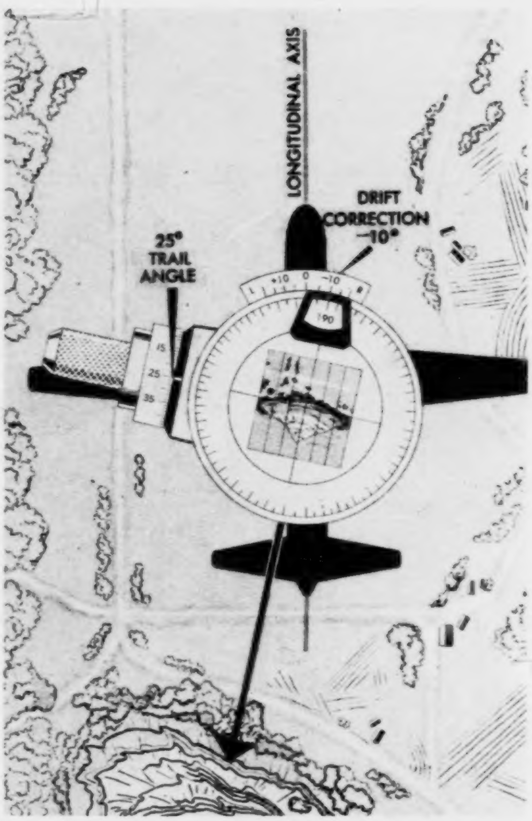
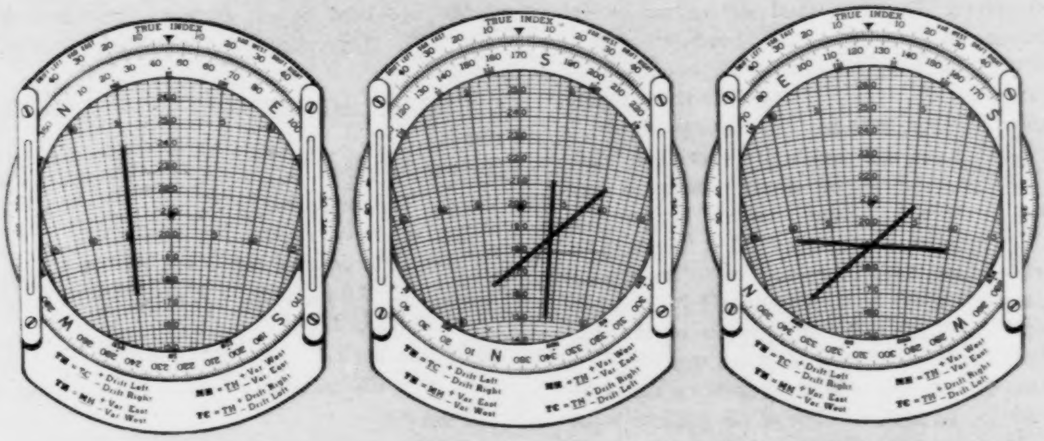


Figure 5-55. At Low Altitude, Use 25° or 50° Trail Angle

As shown in figure 5-55, the aircraft has passed over the mountain. Actually, the navigator is looking down into the instrument; however, he sees the landscape behind the aircraft at a 25° angle. At this angle, the objects do not cross the field of view as fast as they do when looking straight down.

Finally, here are some miscellaneous tips. For high altitude, replace the one-power eyepiece with the three-power eyepiece. If the ground appears too bright, introduce a shade glass into the optical system by means of the shade glass lever.


TRUE INDEX
TRUE INDEX
TRUE INDEX
N
E
S
W
TH = TC + Drift Left − Drift Right
TH = MH + Var East − Var West
MH = TH − Var East + Var West
TC = TH + Drift Right − Drift Left

A. Use track line 5° left of center line.

B. Intersection of two lines is head of wind vector.

C. Rotate compass rose until wind vector is below grommet.

Figure 5-56. Computer Solution for Wind Vector When Drift on Two Headings Is Known

Wind Determination

Wind may be determined without knowing the exact position of the aircraft. The methods of wind determination when the position of the aircraft is not precisely known are discussed under these topics: (1) drift on multiple headings, (2) multiple drift, and (3) groundspeed by timing.

DRIFT ON MULTIPLE HEADINGS. If drift can be read on two headings, the wind can be determined using the wind face of the DR computer.

Sample Problem:

Given: TH^1 045°,
TAS^1 210k,
Drift 5° L(+5°DC)
TH^2 170°,
TAS^2 200k,
Drift 4° R(−4°DC)

To Find: Wind Direction (WD) and Wind Speed (WS)

COMPUTER SOLUTION.

1. Set TH^1 (045°) under the true index and TAS^1 (210k) under the grommet as shown in figure 5-56A.

2. On the transparent circular plate draw a line over the track in the same number of degrees right or left of the center line that drift is right or left. If drift is 5°L, use the track line 5° left of the center line.

3. Set TH^2 (170°) under the true index and TAS^2 (200k) under the grommet (figure 5-56B).

4. Rule a line over the track line (4° right of center) representing Tr^2. The intersection of the two lines is the head of the wind vector; and, for any true heading, this intersection is the head of the track-groundspeed vector.

5. Rotate the compass rose until the head of the wind vector is on the center line below the grommet as shown in figure 5-56C. Read WD (125°) under the true index, and WS (19k) from the grommet to the head of the wind vector.

If drift on another heading is known, rule in another track line on the computer. If the three lines intersect at a point, use that point as the head of the wind vector. If they form a triangle, use the center of the triangle.

Wind by drift on two headings can and should be found when course is altered approximately 45° or more. If the change of heading is less than 45°, a small error in either drift reading may cause a relatively large error in the wind found. For example, assume a wind of 324°/12k. On a true heading of 080° and at a true airspeed of 150 knots, an aircraft drifts 4° right. On a true heading of 100° at the same true airspeed, it drifts 3° right. If you read drift correctly on the first heading and make a 1° error in reading drift on the second heading (reading 2° right instead of 3° right), the computed wind will be 299°/18k.

MULTIPLE DRIFT. Wind determination by measurement of drift on two headings can be used only when a reasonably large change of heading is made. On the other hand, it is quite possible to alter heading long enough to get a drift reading and then return to the original heading. If, for example, the aircraft makes a turn of 45° to the right, remains on this heading for, say, 1½ minutes, then turns 90° left for the same length of time, and finally returns to its original heading, it should be approximately back on its original track after the completion of the maneuver. In the meantime, the navigator will have had the opportunity of reading drifts on the headings of 45° to right and left of his original heading. These, combined with a drift reading made on the original heading, give him three values of drift on three headings to solve for the wind vector on the DR computer. This maneuver is called a *multiple* or *double drift*. Turns of 45° and 90° are used in the example illustrated in figure 5-57. There are other variations to this procedure.

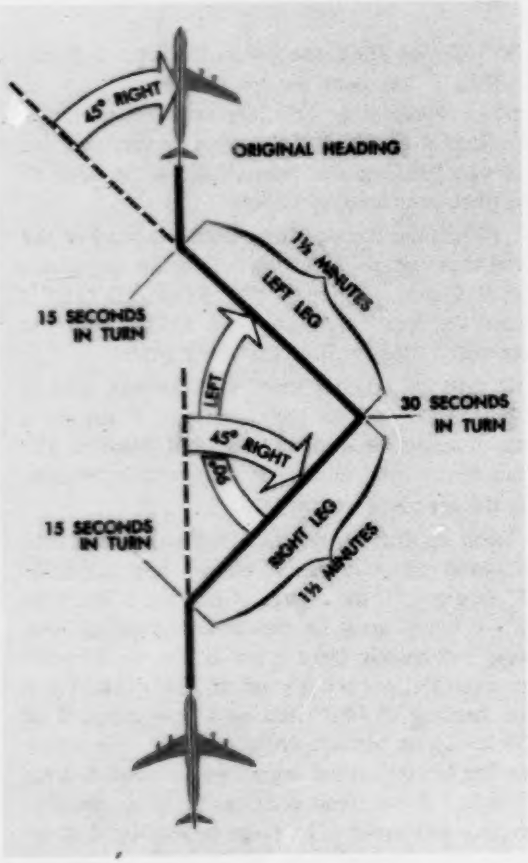


Figure 5-57. Procedure for Multiple Drift

COMPUTER SOLUTION OF MULTIPLE DRIFT.

Sample Problem:

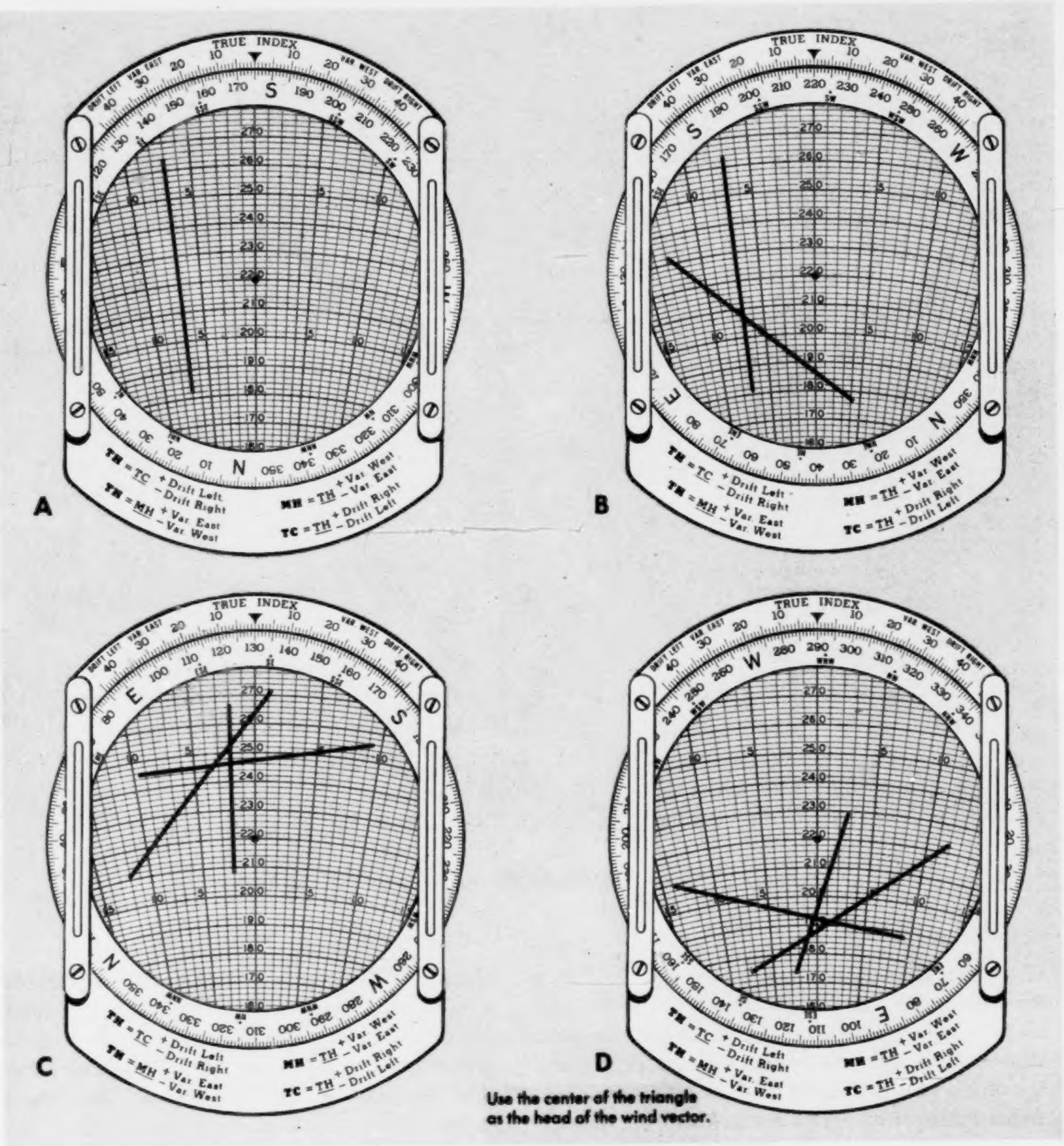
Given: TH on course, 175°
Drift on course, 7°L (+7°DC)
Drift on right leg, 7°L (+7°DC)
Drift on left leg, 2°L (+2°DC)
TAS, 220k

To Find: W/V
GS on course

Set in the data:

1. Set on-course TH (175°) under the true index and TAS (220k) under the grommet as shown in figure 5-58A.
2. On the transparent plate, draw a line over the drift line (7° left of center) representing track. Remember that track is the same number of degrees right or left of the center line as drift.
3. Rotate the compass rose 45° left, that is, until the on-course TH (175°) is under the 45° left-drift mark. Then the right-leg TH (220°) is automatically under the true index (see figure 5-58B).
4. Draw a line over the drift line (7° left of center) representing the right-leg track.
5. Rotate the compass rose 90° right, that is, until the on-course TH (175°) is under the 45° right-drift mark. Then the left-leg TH (130°) is automatically under the true index (see figure 5-58C).
6. Draw a line over the drift line (2°) left of center, representing the left-leg track. Note that the three drift lines in this illustration form a small triangle. Use the center of the triangle as the head of the wind vector.
7. Rotate the compass rose until the head of the wind vector is on the center line below the grommet. Now read WD (290°) under the true index, and read WS (30k) from the grommet to the head of the wind vector (see figure 5-58D).
8. Set on-course TH (175°) under true index and the grommet on TAS (220k). Read on-course GS (234k) at the speed circle passing through the head of the wind vector.

Remember, when flying a multiple drift, check the compass on each heading to be sure the pilot has turned correctly. Also, when turning 45° and using the drift scale in setting up the com-



Use the center of the triangle as the head of the wind vector.

Figure 5-58. Computer Solution of Multiple Drift

puter, it is easy to turn the disk in the wrong direction. If the turn is to the right, the computer is turned counterclockwise, because the heading increases. Be sure to take enough time to get an accurate drift reading.

GROUNDSPEED BY TIMING. The method of computing the wind vector when the true heading-true airspeed vector and the track-groundspeed vector are known has been explained. Track can be found by applying drift to true heading. Groundspeed can also be found with the driftmeter by the method known as *groundspeed by timing*. Thus, the wind can be found without knowing the exact position of the aircraft and without altering heading.

Groundspeed by timing is a method of determining groundspeed by measuring the time in which an object on the ground appears to move

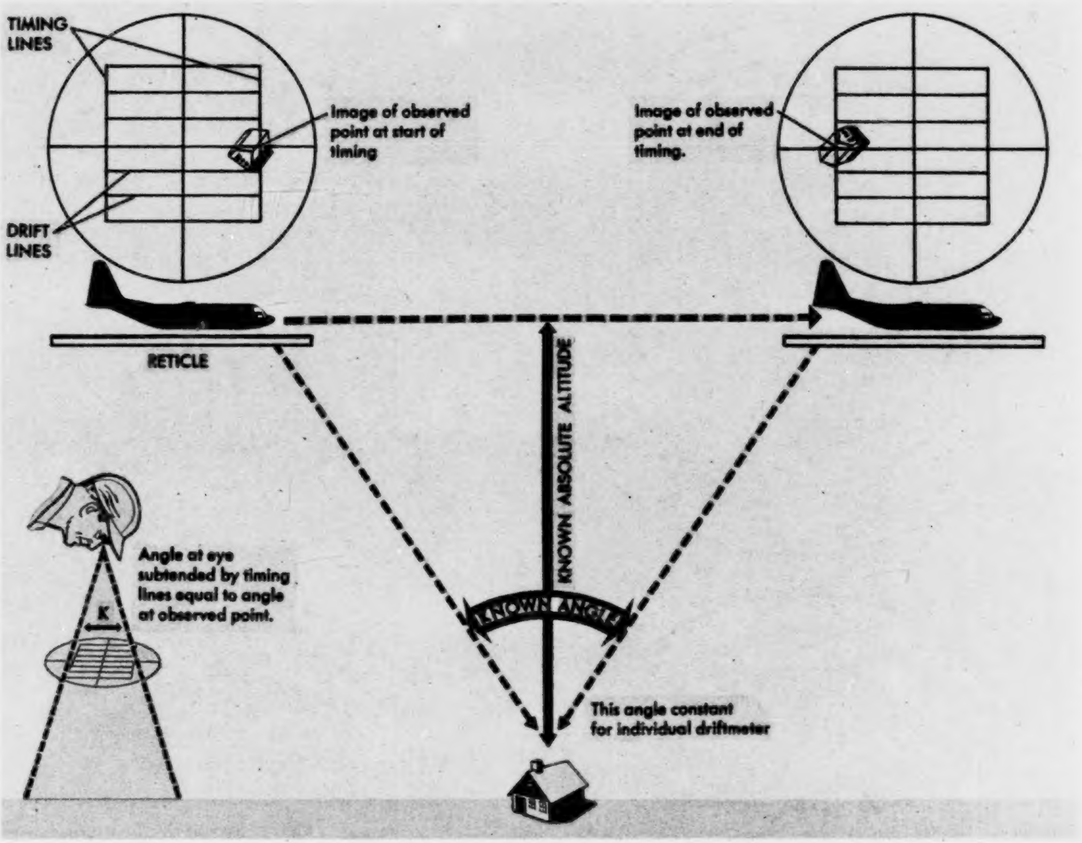

TIMING LINES
Image of observed point at start of timing
Image of observed point at end of timing.
DRIFT LINES
RETICLE
KNOWN ABSOLUTE ALTITUDE
Angle at eye subtended by timing lines equal to angle at observed point.
K
KNOWN ANGLE
This angle constant for individual driftmeter

Figure 5-59. Groundspeed by Timing, Zero Trail Angle Method

through a known angle when the aircraft is at a known altitude. This is shown in figure 5-59. The angle is measured with a driftmeter and the time with a stopwatch. In addition to the drift lines, the reticle of a driftmeter has two transverse lines called timing lines. With a stopwatch the passage of an object can be timed from one timing line to the other; that is, through an angle which is constant for that driftmeter. The distance traveled by the aircraft as the object passes through this angle is proportional to the absolute altitude (AA —altitude above the terrain) of the aircraft. Knowing the absolute altitude and the angle, this distance can be computed by trigonometry. Then, from the distance and time, the groundspeed may be computed.

However, trigonometry isn't needed to work out a groundspeed by timing problem. Since the distance traveled is proportional to the absolute altitude, it is found by multiplying the absolute altitude by a factor (called the K-factor) which is constant for the individual driftmeter. The groundspeed is solved on the DR computer using time in seconds, absolute altitude, and the K-factor.

The accuracy of groundspeed by timing depends on the accuracy of the timing and on the accuracy of the absolute altitude. A 10 percent error in either time or absolute altitude can cause a 10 percent error in groundspeed. With a given groundspeed, the time for an object to pass between the timing lines increases with the altitude. As altitude and time increase, a given error in time will result in a smaller error in groundspeed. Therefore, the greater the absolute altitude, the more accurate will be the results. Ordinarily, the stopwatch timing should be accurate to about one-tenth of a second.

Absolute Altitude. The determination of absolute altitude often is a source of inaccuracy. The accuracy of this determination depends on the nature of the terrain and on the type of altimeter used. In level flight over the sea, the absolute altitude remains nearly constant, but over rough terrain, it changes continuously. Therefore, absolute altitude can be found more easily and more accurately over the sea than over rough terrain.

Absolute altitude can be read directly from an absolute altimeter. Such an instrument is an altimeter based on the reflection of radio waves and is discussed in detail later in the manual. If a pressure altimeter is used, the terrain elevation must be subtracted from the basic true altitude to find absolute altitude. With an absolute altimeter, groundspeed by timing can be done over the sea or over relatively flat terrain without knowing the position of the aircraft.

However, with a pressure altimeter, the terrain elevation must be known (when over land) to do groundspeed by timing. To know the terrain elevation, an accurate chart is necessary; moreover, the timing must be accomplished in an area where the elevation is marked on the chart. The more uneven the terrain, the more accurately the position must be known. From this it is easy to see why the absolute altimeter is a better instrument for groundspeed by timing.

Two methods of obtaining groundspeed by timing are given.

Zero Trail Angle Method

1. Uncage the gyro.
2. Read drift and leave the pointer on the drift reading.
3. With a stopwatch, record the time required for a sighted object to pass from one timing line to the other. In addition to the two timing lines near the ends of the drift lines, there is a third transverse line at the center of the field. For the zero trail angle method, use the outer lines.
4. To solve for groundspeed in knots use the following formula:

$$\begin{matrix}\text{Groundspeed} \\ \text{in knots}\end{matrix} = K\left(\frac{\text{Absolute Altitude in feet}}{\text{Time in seconds}}\right)$$

The K-factor is stamped on a plate which is fastened to the gyro housing. For solution on the computer, write the formula as a proportion:

$$\frac{\text{GS}}{\text{K}} = \frac{\text{Absolute Altitude}}{\text{Time}}$$

Example:

Absolute Altitude 10,000 feet
Time in seconds 7.3
K-Factor .159

Set up the proportion on the computer as follows:

$$\frac{\text{GS}}{.159} = \frac{10{,}000}{7.3}$$

Set 7.3 on the minutes scale under 10,000 on the miles scale. Read the groundspeed (217) on the miles scale over .159 as shown in figure 5-60.

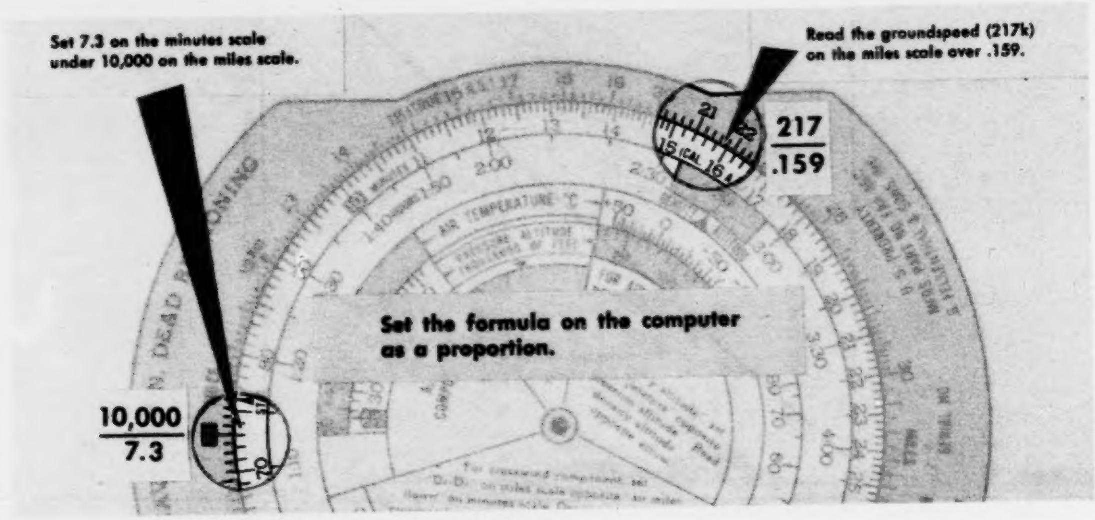

Set 7.3 on the minutes scale under 10,000 on the miles scale.
Read the groundspeed (217k) on the miles scale over .159.
217
.159
Set the formula on the computer as a proportion.
10,000
7.3

Figure 5-60. Groundspeed by Timing, Computer Solution

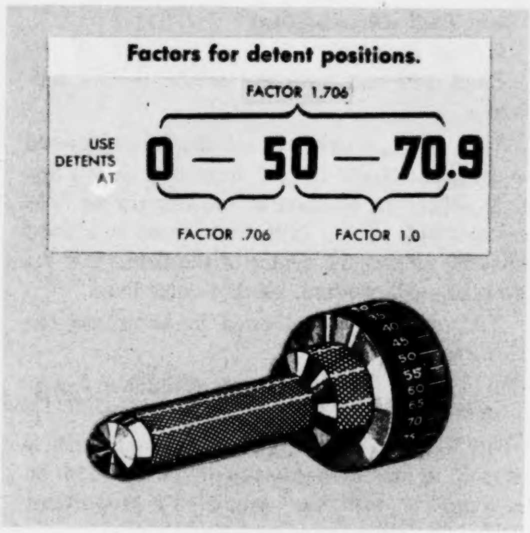

Factors for detent positions.
FACTOR 1.706
USE DETENTS AT
0 — 50 — 70.9
FACTOR .706
FACTOR 1.0
40
45
50
55
60
65
70

Figure 5-61. Line-of-Sight Knob Detent Positions

Trail Angle Method, 0°—50°

The line-of-sight control handle has detents or partial stops at three trail angles (refer to figure 5-61). As the line of sight reaches one of these angles, the detent can be felt and heard. By changing the line of sight from one detent to another, the passage of an object can be timed from the center timing line at one trail angle to the center timing line at another trail angle.

The trail angle method of groundspeed by timing is described in detail for use with the 0° and 50° detents. The method is the same with the 50° and 70.9° detents or the 0° and 70.9° detents.

1. Read drift and leave the pointer on the drift reading.
2. Turn the line of sight to the 0° detent. Start the stopwatch as an object crosses the center timing line.
3. Turn the line of sight, keeping the object in view until the 50° detent is felt. Stop the watch just as the same object crosses the center line again. (See figure 5-62.)
4. Read or compute the absolute altitude. If possible, absolute altitude should be read when the object is directly beneath the aircraft.
5. Obtain the correct factor. The factor is 1.00 for the angle from 50° to 70.9°. For the angle from 0° to 50°, the factor is 0.706; for the angle for 0° to 70.9°, it is 1.706. These factors are for groundspeed in knots.

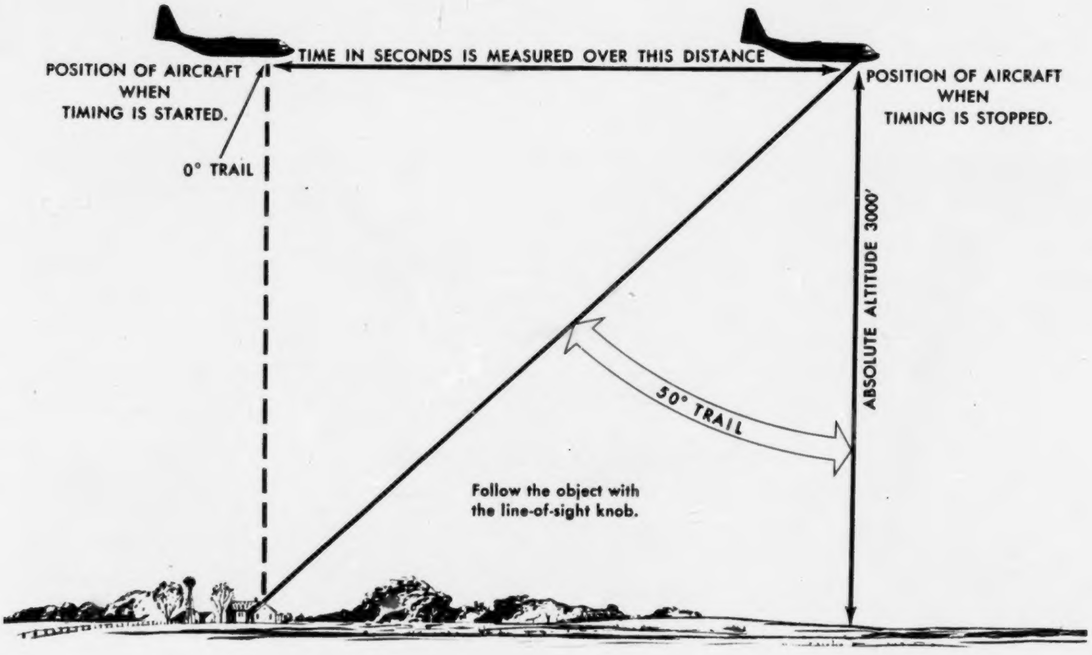

TIME IN SECONDS IS MEASURED OVER THIS DISTANCE
POSITION OF AIRCRAFT WHEN TIMING IS STARTED.
POSITION OF AIRCRAFT WHEN TIMING IS STOPPED.
0° TRAIL
ABSOLUTE ALTITUDE 3000'
50° TRAIL
Follow the object with the line-of-sight knob.

Figure 5-62. Groundspeed by Timing, 0° to 50° Trail Angle Method

TRAIL ANGLE METHOD (B-3 DRIFTMETER)

FINISH IN °	START *0°	10°	20°	30°	40°	50°
5°	.0518					
10	.1043					
15	.1587	.0543				
20	.2155	.1112				
25	.2761	.1717	.0605			
30	.3419	.2375	.1264			
35	.4146	.3102	.1990	.0727		
40	.4968	.3924	.2813	.1549		
45	.5921	.4877	.3765	.2502	.0953	
*50	.7057	.6013	.4901	.3638	.2089	
55	.8456	.7412	.6300	.5037	.3487	.140
60	1.026	.9222	.8100	.6837	.5287	.320
65	1.270	1.165	1.054	.9275	.7729	.564
*70.9	1.706	1.602	1.490	1.364	1.209	1.000

*B-3 Driftmeter has detents at these angles.

Figure 5-63. K-Factors for Groundspeed by Timing

6. Using the following formula, solve for the groundspeed.

$$\frac{GS}{K} = \frac{\text{Absolute Altitude}}{\text{Time}}$$

The same procedure may be used with trail angles where there are no detents. If this is done, it is necessary to note the value of the angle at the beginning of the run and at the end. Using these angles, the factor can be obtained from the table, *K-Factors for Groundspeed by Timing* (see figure 5-63).

The trail angle method is preferable to the zero trail angle method because the length of the timing period is increased. Consequently, the groundspeed will be more accurate because errors in timing will not be magnified as much as they are with the shorter period of time.

Finding Wind After Groundspeed By Timing. After finding the groundspeed, it is an easy matter to find the wind. Since the true heading-true airspeed vector and the track-groundspeed vector are known, the wind triangle problem can be solved on the computer.

CHAPTER 6

Lines of Position, Bearings and Fixes

BEARINGS AND LINES OF POSITION

Dead reckoning is fundamental to navigation. DR positions based solely on time, speed, and direction are the foundations of navigation. The skill of the navigator depends upon his ability to measure, interpret, correct, and translate these data into useful and reliable information. Dead reckoning is seldom exact, and the longer DR is carried from a fix, the less reliable it becomes. Individual small errors tend to accumulate until the total error becomes dangerously large.

To keep the total error at a minimum, a competent navigator employs every means of finding his actual position in relation to the ground. In flights over land, with suitable visibility, an air navigator can frequently identify his position by means of recognizable landmarks. An accurate position determined without reference to any former position is called a *fix*.

If a fix is well defined, the navigator knows his position as precisely as at the time he took off. Such a fix serves as a new point of departure, canceling all previous errors in DR and becoming the origin of a new DR plot. A series of fixes improves the accuracy of later DR positions by giving better information concerning track, groundspeed, and wind.

Lines of Position

A navigator often has knowledge of his position without knowing precisely where he is. For example, he might recognize a river crossed in flight without knowing exactly where the crossing was made. He then has a definite clue to his position, but he does not have a fix. A fix is a point; the river is a line. A line indicating a series of possible positions of the aircraft is called a *line of position (LOP)*.

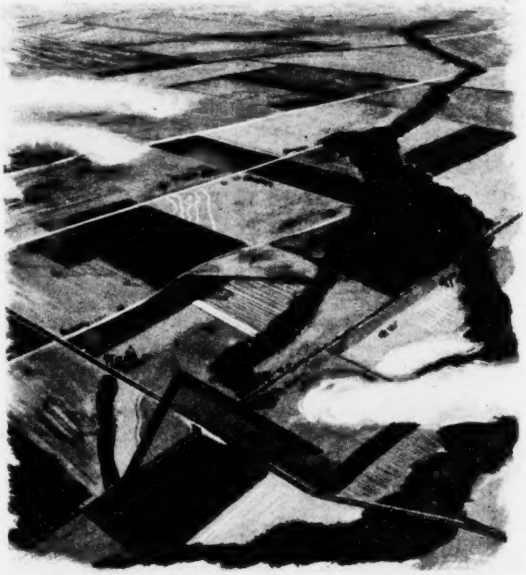


Figure 6-1. Two Intersecting LOPs Establish a Fix

If a navigator can identify his position along an LOP, he then has a fix. Suppose a navigator is flying above a railroad as illustrated in figure 6-1. Even if he does not have an exact position along the railroad, he has a visual LOP. He is somewhere along this line. Now if he sees the railroad cross another railroad below the aircraft, he then knows exactly his position on the two railroads and has a fix. Thus, two intersecting LOPs establish a fix.

LINES OF POSITION BY BEARINGS. A common method of determining a line of position is to establish the direction of the line of sight to a

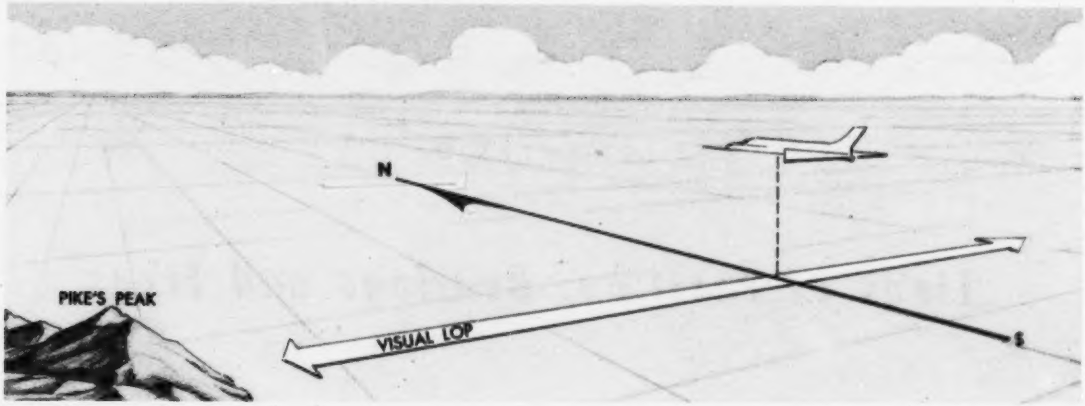


Figure 6-2. Establish a Visual LOP

known, fixed object by means of a driftmeter. The illustration in figure 6-2 shows a line of sight from the aircraft to a fixed object on the ground. The direction of the line of sight is the *bearing* of the object from the aircraft. A line plotted in the direction of the bearing is a line of position. At the time of the observation, the aircraft must have been on the line of position; otherwise the bearing would have been different. A bearing is a locus of possible positions of the aircraft.

RELATIVE BEARINGS. A relative bearing is the angle between the fore-and-aft axis of the aircraft and the line of sight to the object, always measured clockwise from 000° at the nose of the aircraft, through 360°. In figure 6-3, the relative bearing of the object is shown as 070°. Before the relative bearing is plotted, it must be converted to true bearing by adding to it the momentary true heading of the aircraft when the bearing was taken (dropping 360° when the sum exceeds this amount). Thus:

$$TB = RB + TH$$

Where:

TB is the true bearing,
RB is the relative bearing, and
TH is the true heading.

Assuming the aircraft to be on a true heading of 210° when the bearing was taken, the corresponding true bearing of the object is 280°.

The basic equation for TB may be rearranged to compute any other item it contains. Thus:

$$TH = TB - RB,$$

or

$$RB = TB - TH.$$

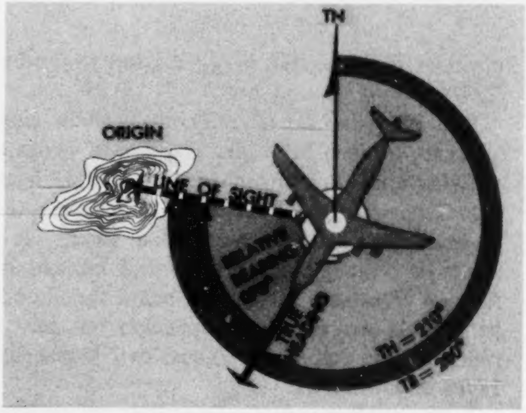
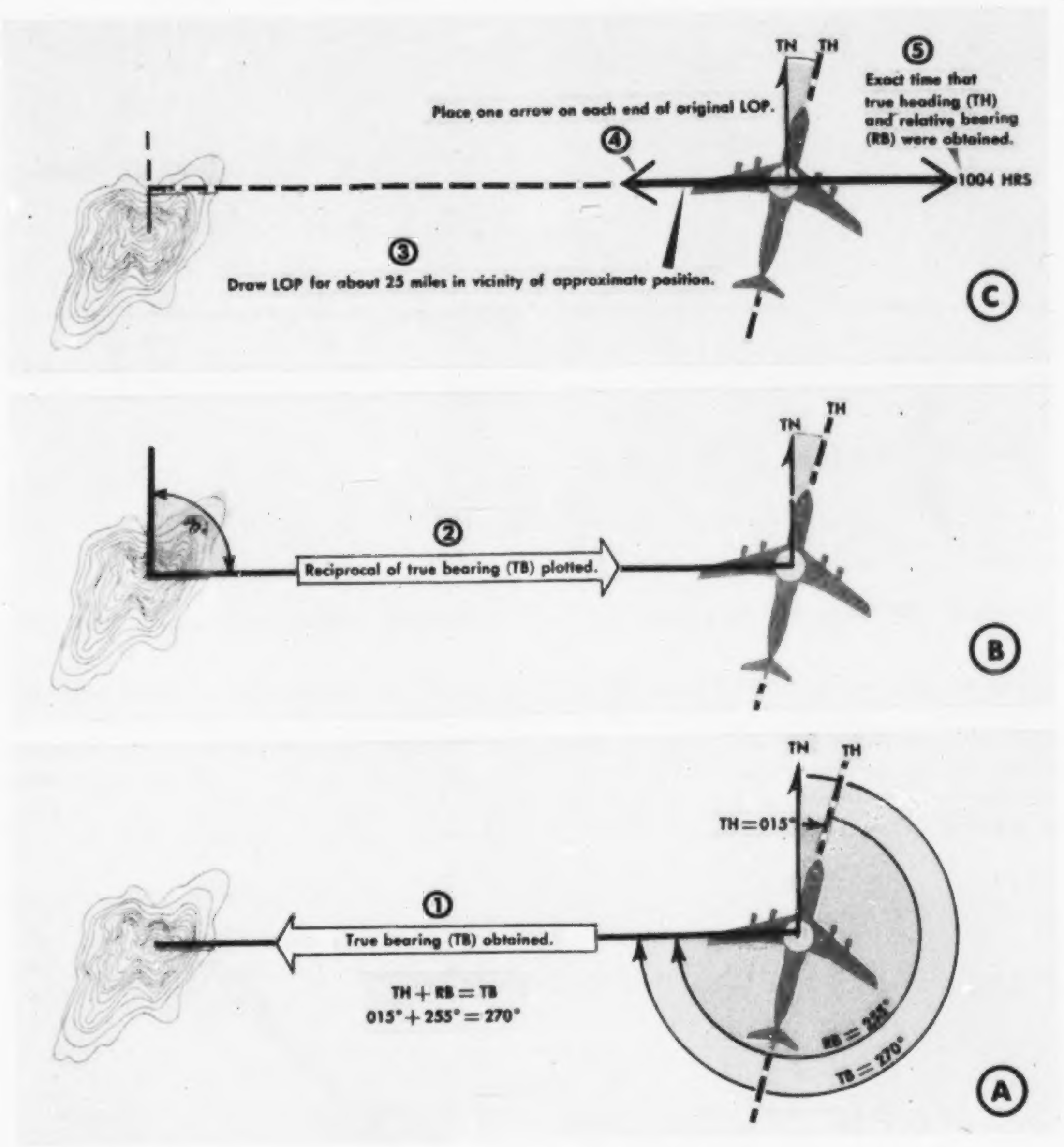


Figure 6-3. True Bearing Equals Relative Bearing Plus True Heading

Plotting the LOP

As previously stated, two intersecting LOPs determine the position of the aircraft. The only other possible point from which to begin the plotting is the object on which the bearings were taken. The procedure is to use the reciprocal of the true bearing of the object, thus drawing an LOP toward the aircraft. In actual practice, it is not necessary to compute the reciprocal of the bearing; the true bearing is measured with the plotter, and the LOP is drawn towards the opposite end of the plotter.



TN
TH
⑤
Exact time that true heading (TH) and relative bearing (RB) were obtained.
Place one arrow on each end of original LOP.
④
1004 HRS
③
Draw LOP for about 25 miles in vicinity of approximate position.
C
TN
TH
TB
②
Reciprocal of true bearing (TB) plotted.
B
TN
TH
TH=015°
①
True bearing (TB) obtained.
TH + RB = TB
015° + 255° = 270°
RB = 255°
TB = 270°
A

Figure 6-4. Procedures for Plotting LOP

To establish an LOP by relative bearing, the navigator must know:

- The position of the source of the bearing.
- The true heading of the aircraft.
- The relative bearing of the object.
- The exact time at which the true heading and relative bearings were taken. Figure 6-4 shows the procedure to follow.

Use of LOPs

A fix gives definite information as to both track and groundspeed of an aircraft since the last fix, but a single LOP can define either the track or the groundspeed—not both. It may not clearly define either. The evidence obtained from an LOP depends upon the angle at which it intersects track, and LOPs are sometimes classified according to this angle.

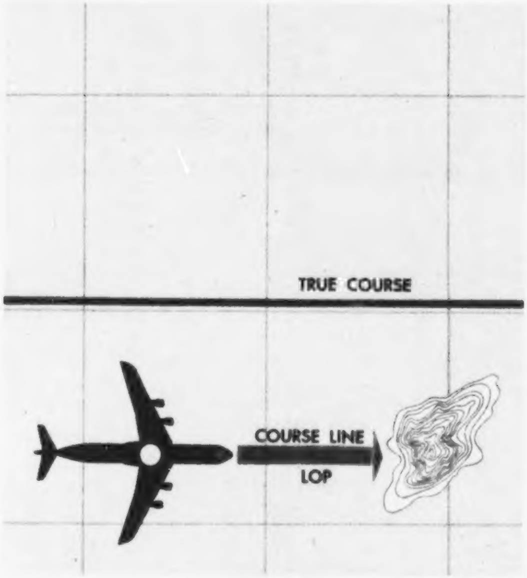

TRUE COURSE
COURSE LINE
LOP

Figure 6-5. LOP Parallel to Track Is Course Line

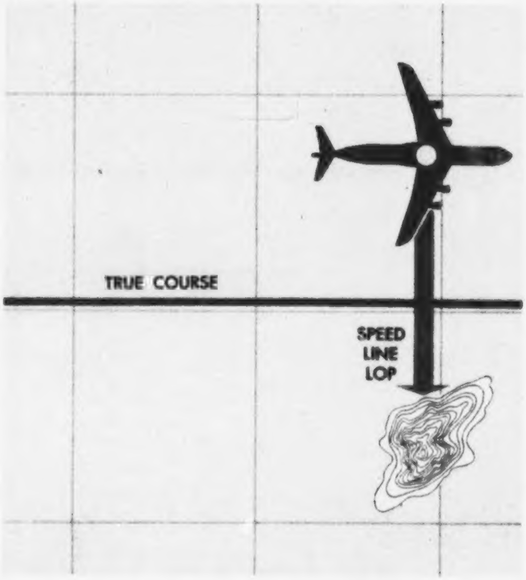

TRUE COURSE
SPEED
LINE
LOP

Figure 6-6. LOP Perpendicular to Track Is Speed Line

Course Line. An LOP which is parallel or nearly parallel to the course is called a course line (figure 6-5). It gives information as to possible locations of the aircraft laterally in relation to the course; that is, whether it is to the right or left of course. Since it does not indicate how far the aircraft is along the track, no speed information is provided.

Speed Line. An LOP which is perpendicular or nearly so to the track is called a speed line (figure 6-6), since it indicates how far the aircraft has traveled along the track, and thus is a

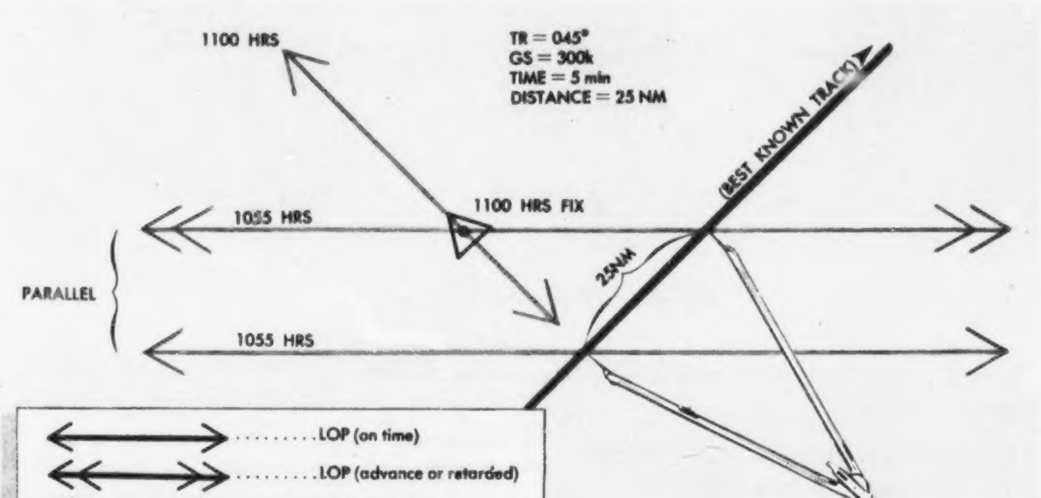

1100 HRS
TR = 045°
GS = 300k
TIME = 5 min
DISTANCE = 25 NM
(BEST KNOWN TRACK)
1100 HRS FIX
1055 HRS
PARALLEL
25NM
1055 HRS
.........LOP (on time)
.........LOP (advance or retarded)
.........Average LOP

Figure 6-7. Adjusting LOPs for Fix

measure of groundspeed. It does not indicate whether the aircraft is to the right or left of the course. When a speed line intersects the track at an angle less than 90°, an accurate groundspeed is obtained only if distance is measured along the track.

FIXES

Adjusting LOPs for a Fix

Sometimes it is impossible for an air navigator without assistance to obtain more than one LOP at a given time. Unless a second LOP is obtained simultaneously, the intersection of the two lines does not constitute a fix because the aircraft is moving between the times of the two observations.

The illustration in figure 6-7 shows a bearing taken at 1055 and another at 1100. At 1055 when the first bearing is taken, the aircraft is somewhere along the 1055 line of position (single barbed LOP), and at 1100 it is somewhere along the 1100 LOP. The intersection of these two lines, as plotted, does not constitute a fix. For an intersection to become a fix, the LOPs must either be observed at the same time or adjusted for the motion of the aircraft between the observations. The usual method of adjusting an LOP for the motion of the aircraft is to advance one line to the time of the other. The illustration in figure 6-7 shows how this is done. The desired time of the fix is 1100.

1. Determine the time to advance the LOP (5 minutes) and multiply this time by the groundspeed of the aircraft (300 knots).
2. Take the distance computed in the first step and lay it off in the direction of the track of the aircraft (45°).
3. Draw a line through this point parallel to the 1055 LOP (double barbed LOP). This represents the advanced LOP. The intersection of the advanced LOP and the 1100 LOP is the fix.

For purposes of plotting, the advanced LOP is usually labeled with two arrowheads, while the unadvanced LOP is marked with a single arrowhead.

When three LOPs are involved, the procedure is exactly the same as for only two. The resolution of three LOPs, however, usually results in a triangle, and the triangle may be large enough to vary the position of the fix considerably. The procedure most universally adopted by Air Force navigators is to place the fix at the center of the triangle. The illustration in figure 6-8 shows the technique for finding the center of the triangle by bisecting the angles of the triangle. The point of intersection of the bisectors is the position of the fix.

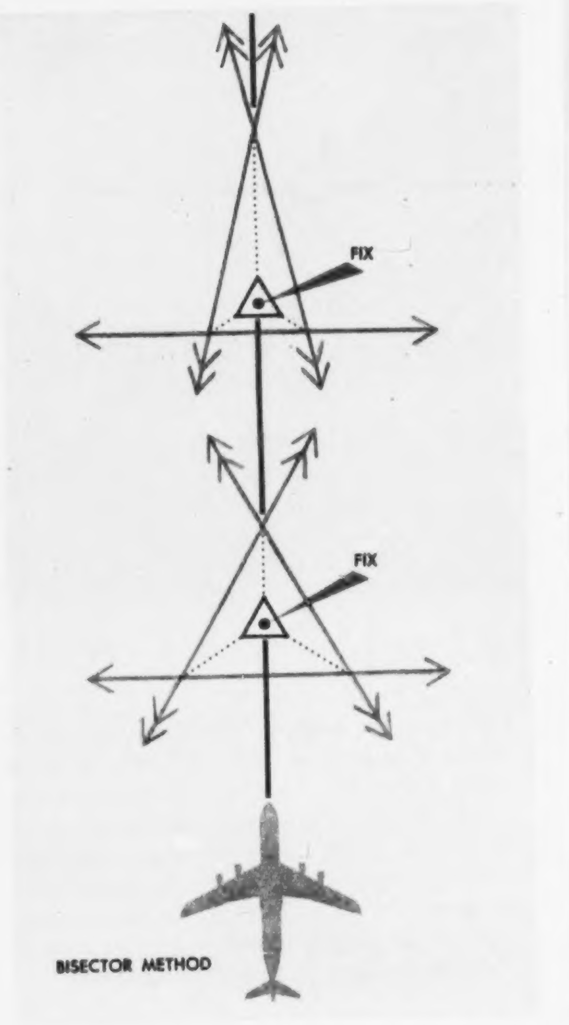


Figure 6-8. Use Center of Triangle for Fix

The Running Fix

It is possible to establish an aircraft position by a series of bearings on the same object. For best accuracy, these relative bearings are taken when the object is approximately 45°, 90°, and

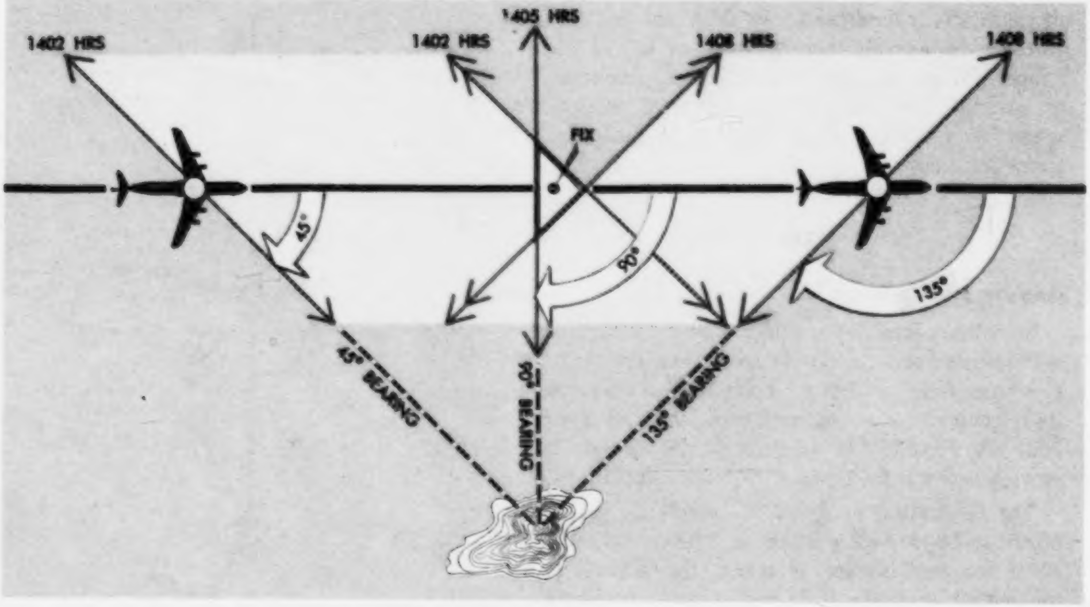


Figure 6-9. The Running Fix

135° from the aircraft. The lines are then advanced or retarded to the same time. The resulting fix is termed a *running fix*, though the position is actually not an absolutely reliable fix because the advance of the earlier line is dependent upon track and groundspeed which may not be known precisely. For short intervals, the error is small, and the accuracy is almost equivalent to a fix. The running fix is illustrated in figure 6-9.

Accuracy of a Fix

The accuracy of a fix can sometimes be improved by the use of a little foresight. If the direction of motion is known more accurately than the groundspeed, a course line should be adjusted since any error in the groundspeed will have little effect on the position of the adjusted line. If, however, it is desired to adjust a speed line under these conditions, the accuracy of the fix is in doubt. Similarly, if the groundspeed is known more accurately than the track, the speed line should be adjusted to the time of the course line. The line which will be affected least by the information in doubt is the line which should be adjusted.

CHAPTER 7

Map Reading

Map reading is the determination of aircraft position by matching terrain or manmade features with their corresponding symbols on a chart. It is one of the more basic aids to DR. The degree of success in map reading depends upon the navigator's proficiency in chart interpretation, his ability to estimate distance, and the availability of landmarks.

CHECK POINTS

Check points are landmarks used to fix the position of the aircraft or to check on its position and direction of travel. Basically, a check point is a fix that has been anticipated, and the position of the fix, relative to its anticipated position, is the main information derived. Arrival over check points at anticipated times is a confirmation of the accuracy of the wind prediction and indicates reliability of the predicted track and groundspeed. If check points are crossed but not at the predicted time, the groundspeed is in error. If the aircraft passes near but not over a check point, the track anticipated was not made good.

The prudent navigator is quick to observe and evaluate the differences between predictions and actualities in flight. He does not ignore even small variations from anticipated performance, for these are the factors that influence his future judgment. Small errors can become cumulative and may eventually result in the aircraft becoming lost.

If the navigator is doubtful of his position, he must look for related details before the check point can be positively identified. Generally it is better to select a feature of the chart and then seek it on the ground, rather than to work from the ground to the chart. The chart does not show all the detail which is on the ground.

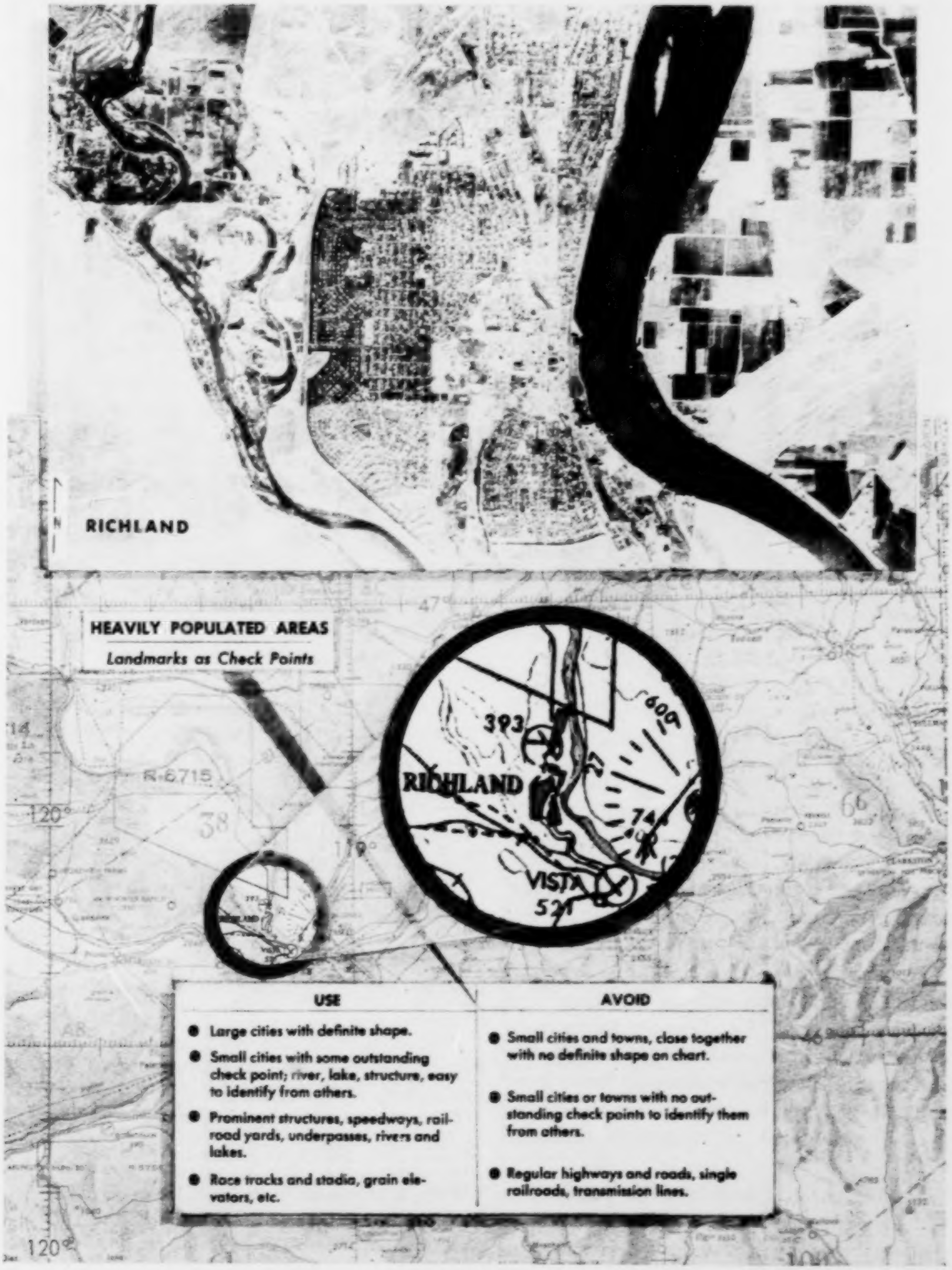
Check points should be features or groups of features which stand out from the background and are easily identifiable. In open areas, any town or road intersection can be used; however, these same features in densely populated areas are difficult to distinguish. Figures 7-1, 7-2, 7-3, and 7-4 compare various chart and corresponding photo areas and list the features to look for when identifying landmarks as check points.

MAP READING PROCEDURES

When in flight, orient the chart so that north on the chart is toward true north. The course line on the chart will then be aligned with the intended course of the aircraft so that landmarks on the ground appear in the same relative position as the features on the chart. Obtain the approximate position of the aircraft by DR. Select an identifiable landmark on the chart at or near the DR position. It is important to work from the chart to the ground since the chart may not portray all of the features visible on the ground. Identify the landmark selected and fix the position of the aircraft.

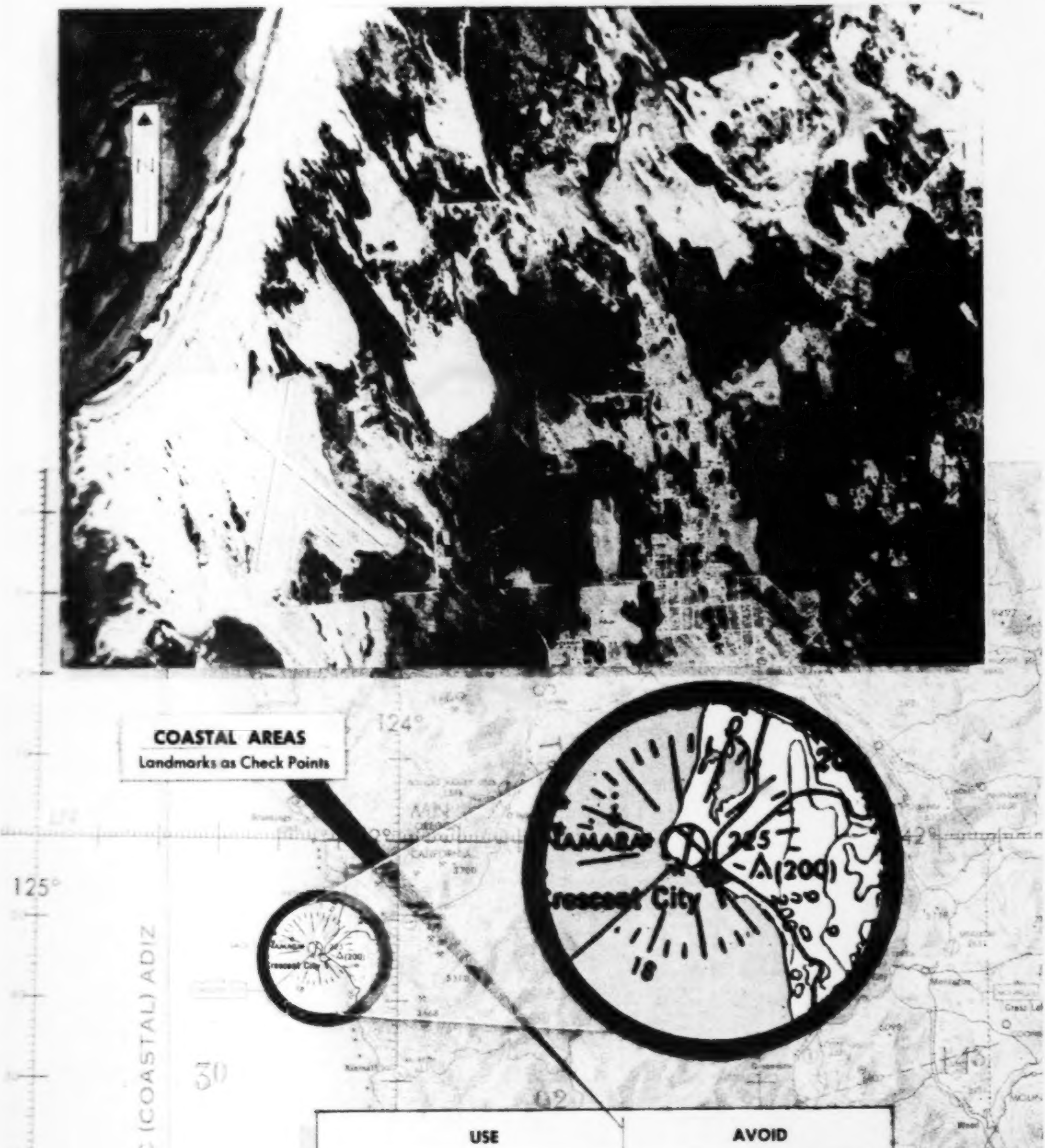
When there is any uncertainty of position, every possible detail should be checked before identifying a check point. The relative positions of roads, railroads, airfields, and bridges make good check points. Intersections and bends in in roads, railroads, and rivers are equally good. When a landmark is a large feature such as a major metropolitan area, select a small prominent check point within the large landmark to fix the position of the aircraft.

When a landmark is not available as a reference


RICHLAND
HEAVILY POPULATED AREAS
Landmarks as Check Points
47°
R-6715
38
120°
119°
393
600
RICHLAND
74
VISTA
521
66
46
120°

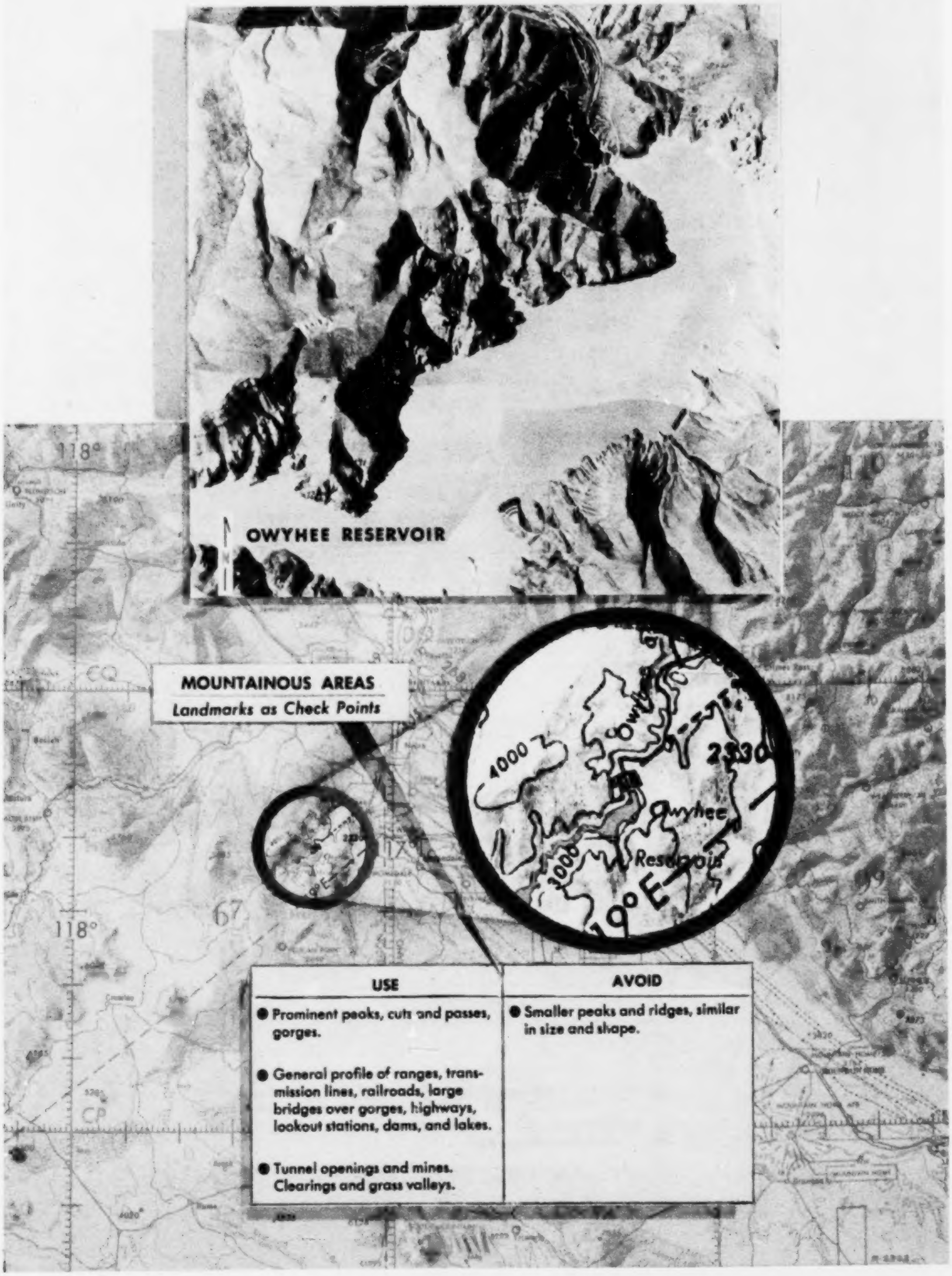
USE	AVOID
Large cities with definite shape.	Small cities and towns, close together with no definite shape on chart.
Small cities with some outstanding check point; river, lake, structure, easy to identify from others.	Small cities or towns with no outstanding check points to identify them from others.
Prominent structures, speedways, railroad yards, underpasses, rivers and lakes.	
Race tracks and stadia, grain elevators, etc.	Regular highways and roads, single railroads, transmission lines.

Figure 7-1. Landmarks as Check Points, Heavily Populated Areas


COASTAL AREAS
Landmarks as Check Points
124°
125°
PACIFIC (COASTAL) ADIZ
30
Crescent City
(200)
18
41°
123°

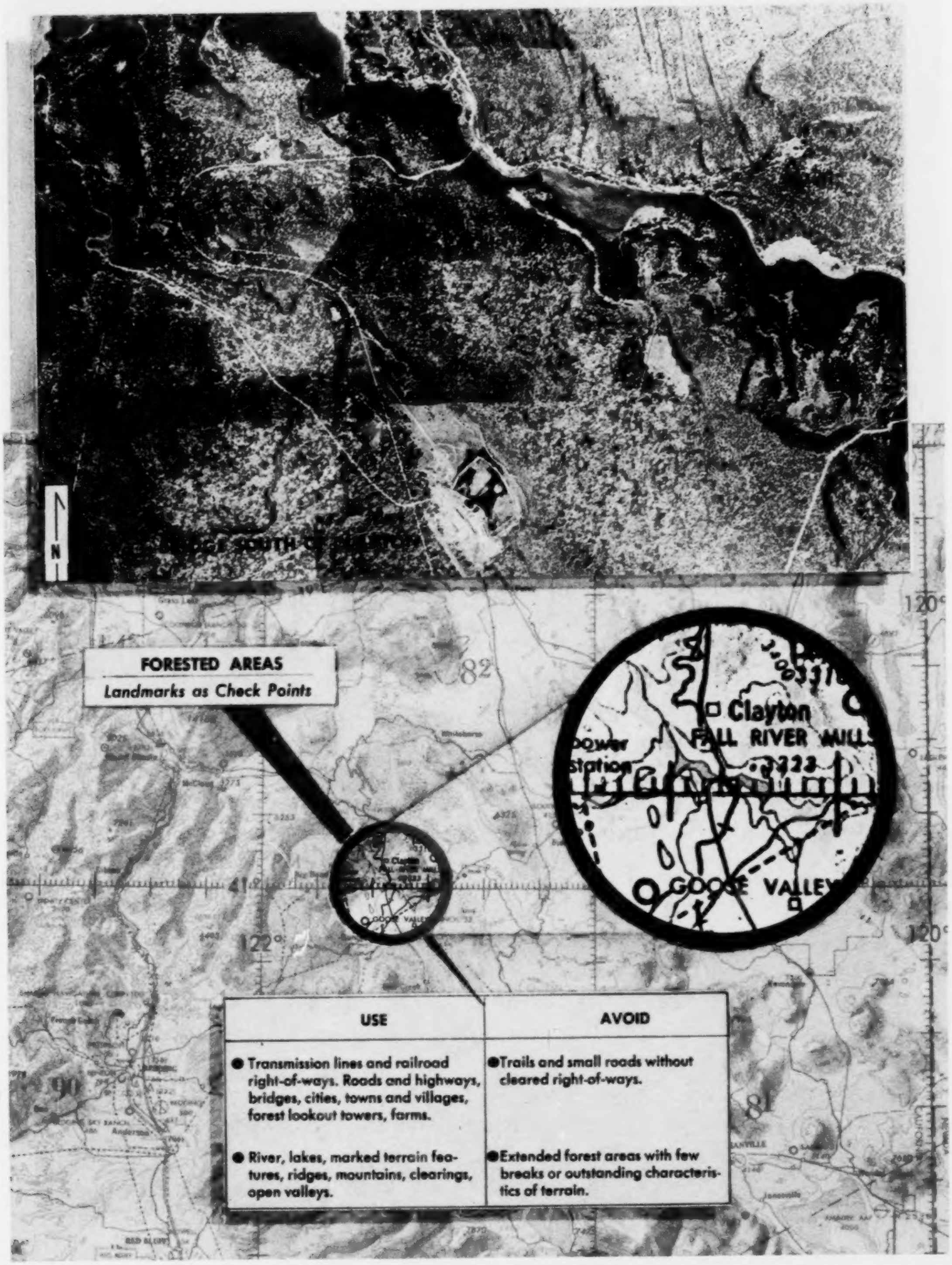
USE	AVOID
● Coastline with unusual features. ● Lighthouses, towns, cities, structures, distinct islands and reefs.	● General rolling coastline with no distinguishing points.

Figure 7-2. Landmarks as Check Points, Coastal Areas


OWYHEE RESERVOIR
MOUNTAINOUS AREAS
Landmarks as Check Points
118°
118°
67
4000
Owyhee
Owyhee
Reservoir
2330
3000
19°E

USE	AVOID
● Prominent peaks, cuts and passes, gorges. ● General profile of ranges, transmission lines, railroads, large bridges over gorges, highways, lookout stations, dams, and lakes. ● Tunnel openings and mines. Clearings and grass valleys.	● Smaller peaks and ridges, similar in size and shape.

Figure 7-3. Landmarks as Check Points, Mountainous Areas


N
SOUTH OF
Clayton
FALL RIVER MILLS
power station
3223
GOOSE VALLEY
82
81
90
41
122°
120°

FORESTED AREAS

Landmarks as Check Points

USE	AVOID
● Transmission lines and railroad right-of-ways. Roads and highways, bridges, cities, towns and villages, forest lookout towers, farms.	●Trails and small roads without cleared right-of-ways.
● River, lakes, marked terrain features, ridges, mountains, clearings, open valleys.	●Extended forest areas with few breaks or outstanding characteristics of terrain.

Figure 7-4. Landmarks as Check Points, Forested Areas

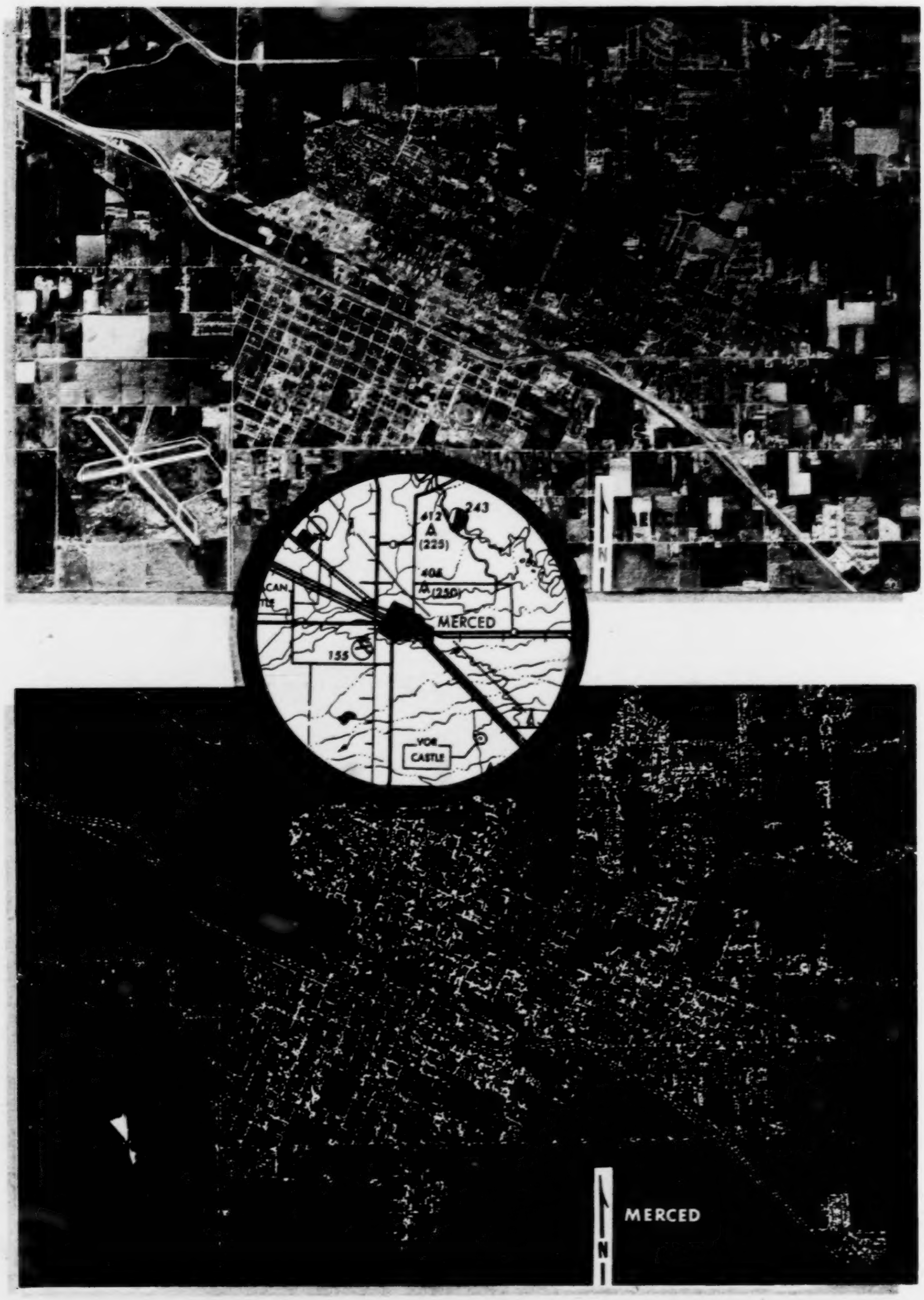

243
612
(225)
408
(250)
MERCED
155
VOR
CASTLE
N
MERCED
N

Figure 7-5. Landmarks at Night

at a scheduled turning point, make the turn on the ETA. Extend the DR position to the next landmark and fix the position of the aircraft to make sure the desired course and groundspeed are being maintained.

Low Level Map Reading

On low level flights the navigator may encounter additional difficulties. Accurate drift observations are hampered by the speed with which the ground seems to rush by. Air turbulence increases the difficulty of instrument observations. The circle of visibility is reduced, and those objects that are visible disappear so rapidly that only the boldest outlines and most conspicuous patterns can be recognized.

In low level navigation, preflight planning is especially important as there is little time for inflight computations. The courses should be laid out to take full advantage of prominent check points. It is sometimes desirable to draw drift lines 5° on each side of the course line to assist the navigator in estimating drift and making necessary corrections.

A prominent landmark such as a high mountain peak or a tower may provide convenient heading references if ahead of the aircraft. Sometimes a coastline, river, highway, or railroad can be followed.

In low level flight, one should be particularly alert to possible danger from obstructions. Hills and mountains are easily avoided if the visibility is good. Radio and television masts, which may extend as much as 1,000 feet or more into the air, often from elevated ground, are less conspicuous. All such obstructions may or may not be shown on the aeronautical charts being used.

Map Reading at Night

During hours of darkness, an unlighted landmark may be difficult or impossible to see. Lights can be confusing because they appear closer than they really are. Fixing on points other than those directly beneath the aircraft is very difficult. Objects are more easily seen by scanning or looking at them indirectly; this eliminates the eye's visual blind spot commonly encountered at night. The navigator should preserve his night vision by working with red light.

In moonlight, some of the prominent unlighted landmarks are visible from the air. Coastlines, lakes, and rivers are usually seen without difficulty. Reflected moonlight often causes a river or lake to stand out brightly for a moment, but this condition is usually too brief for accurate fixing. By close observation, roads and railroads may be seen after the eyes are accustomed to the darkness.

Lighted landmarks such as cities and towns stand out more clearly at night than in daytime. Figure 7-5 illustrates a typical night view of the Merced, California, area. Large cities can often be recognized by their distinctive shapes. Many small towns are darkened at night and are not visible. Airfields with distinctive light patterns may be used as check points. Military fields use a double white and single green rotating beacon, while civilian fields use a single white and single green rotating beacon. Early in the evening, busy highways are discernible because of automobile headlights.

Estimating Distance

A landmark usually falls right or left of course and the navigator must estimate the distance to it. While the ability to estimate distance from a landmark rests largely in skill and experience, the following methods may be of assistance. One method is to compare the distance to a landmark with the distance between two other points as measured on the chart. Another method, shown in figure 7-6, is to estimate the angle between the aircraft subpoint and the line of sight. The distance in nautical miles from the landmark to the subpoint of the aircraft depends on the sighting angle:

(60°) horizontal distance = absolute altitude × 1.7

(45°) horizontal distance = absolute altitude

(30°) horizontal distance = absolute altitude × .6

Cross-check the validity of the estimate by sighting landmarks on each side of the aircraft and comparing the results.

Seasonal Changes

Seasonal changes can conceal landmarks or change their appearance. Small lakes and rivers may dry up during the summer. Their outlines may change considerably during the wet season. They make good check points, however, because they appear as clear areas.

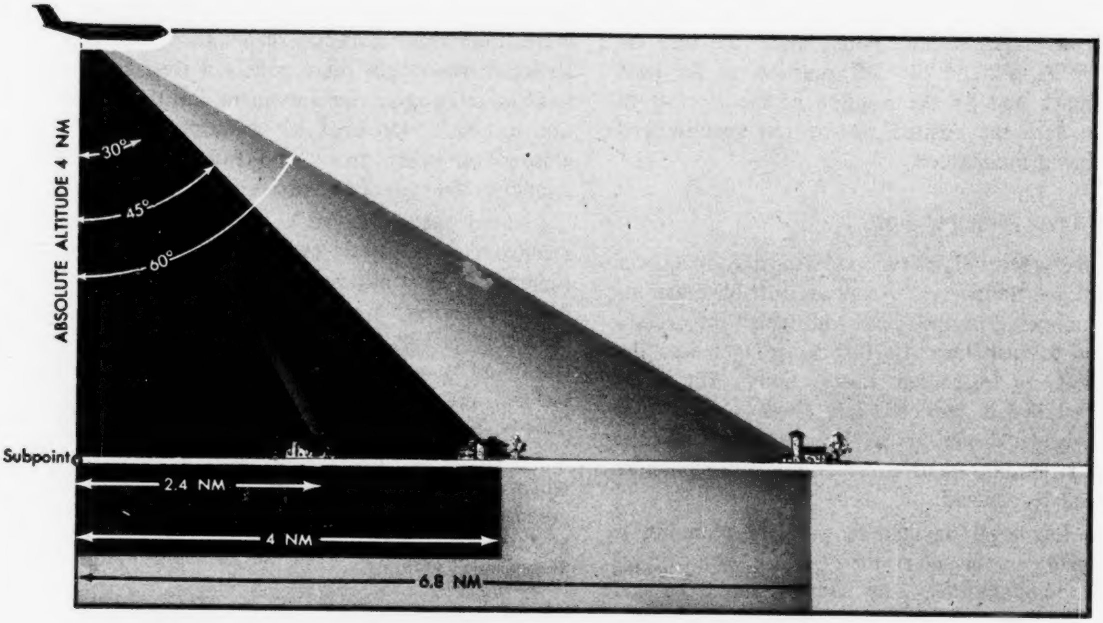


Figure 7-6. Estimating Distances

Map Reading in High Latitudes

Map reading in high latitudes is considerably more difficult than map reading in the lower latitudes. The nature of the terrain is drastically different, charts are less detailed and less precise, and seasonal changes may alter the terrain appearance or hide it completely from view.

In high latitudes, the navigator finds few distinguishable features from which to determine his position. Manmade features are practically nonexistent. The few which do exist are closely grouped, offering little help to the navigator flying long navigation legs. Natural features which exist in limited variety are difficult to distinguish from each other. As illustrated by figure 7-7, lakes seem endless in number and identical in appearance. The countless inlets are extremely difficult to identify, particularly in winter. What appears to be land may in reality be floating ice, the shape of which can change from day to day. Recognizable, reliable check points are few and far between.

Map reading in high latitudes is further complicated by inadequate charting. Some polar areas, as shown in figure 7-7, are yet to be thoroughly surveyed. The charts portray the appearance of general locales, but many individual terrain features are merely approximated or omitted entirely. In place of detailed outlines of lakes, for example, charts often carry the brief annotation, "many lakes." A fix is possible, but requires extended effort and keen judgment on the part of the navigator.

When snow blankets the terrain from horizon to horizon, navigation by map reading becomes acutely difficult. Coastal ice becomes indistinguishable from the land, coastal contours appear radically changed, and many inlets, streams, and lakes disappear.

Blowing snow may extend to heights of 200 to 300 feet and may continue for several days, but visibility is usually excellent in the absence of interfering clouds or ice crystal haze. However, when snow obliterates surface features and the sky is covered with a uniform layer of clouds so that no shadows are cast, the horizon disappears, causing earth and sky to blend together. This forms an unbroken expanse of white called *whiteout.* In this complete lack of contrast, distance and height above ground are virtually impossible to estimate. Whiteout is particularly prevalent in northern Alaska during late winter and spring. The continuous darkness of night presents another hazard; nevertheless, surface features are often visible because the snow is an excellent reflector of light from the moon, the stars, and the aurora.

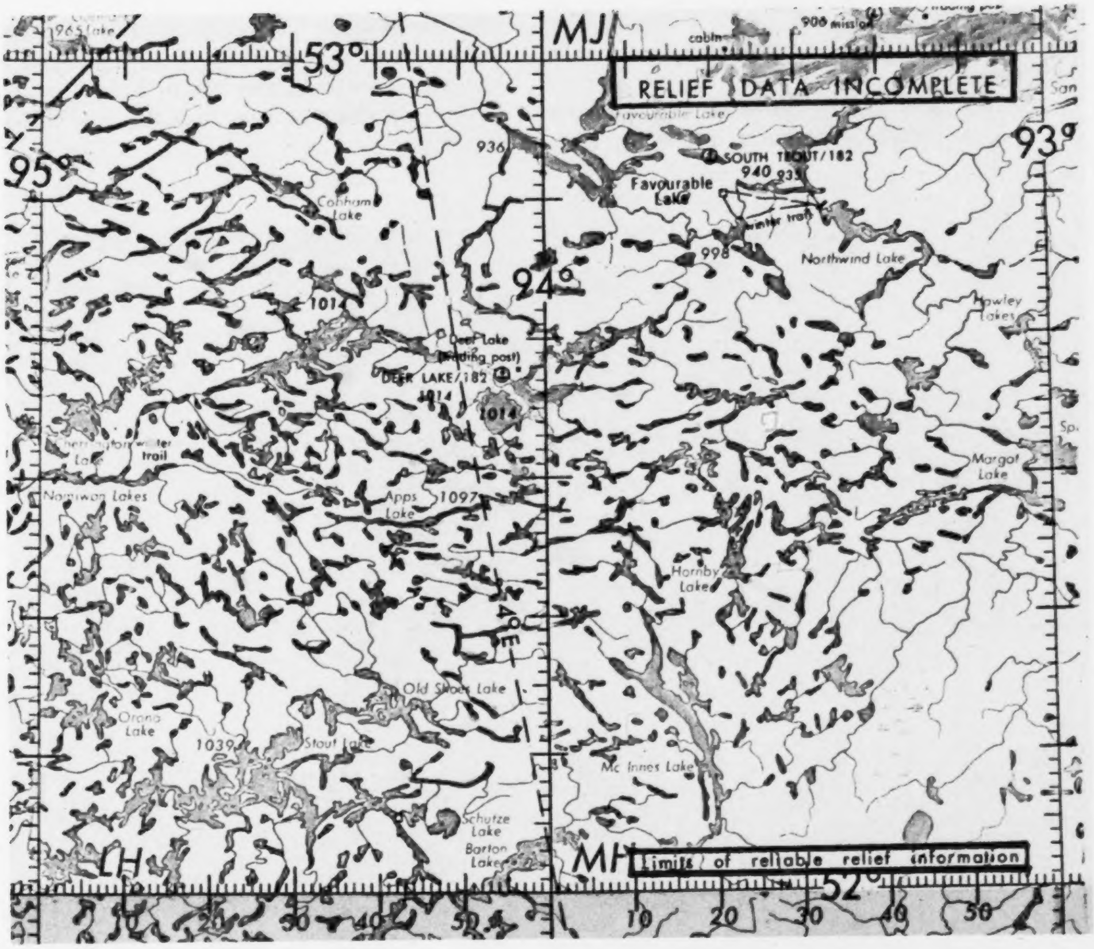

RELIEF DATA INCOMPLETE
Limits of reliable relief information
53°
52°
95°
94°
93°
MJ
MH
LH
Favourable Lake
SOUTH TROUT/182
Northwind Lake
Cobham Lake
Deer Lake (trading post)
DEER LAKE/182
Apps Lake
Hornby Lake
Margot Lake
Hawley Lakes
Old Shoes Lake
Orono Lake
Stout Lake
Mc Innes Lake
Schutze Lake
Barton Lake
Namiwan Lakes
winter trail
936
998
1014
1097
1039
10
20
30
40
50

Figure 7-7. Natural and Cultural Features in High Latitudes

Contour Map Reading

Use of contours is the most common method of showing relief features on a chart. Contours are lines that, at certain intervals, connect points of equal elevation. To understand contours better, think of the zero contour line to be sea level. If the sea were to rise ten feet, the new shore line would be the ten-foot contour line. Similarly, the 20, 30, 40, etc., foot contour lines could be determined. Contour lines are closer together where the slope is steep and farther apart where the slope is gentle. Within the limits of the contour intervals, the height of points can be determined from the chart and the angle of slope can also be determined.

Contour intervals are determined by the scale of the chart, the amount of relief, and the accuracy of the survey. These intervals may range from one foot on a large scale chart through 2,000 feet or greater on a smaller scale chart. Contours may be shown on charts in varying colors and are frequently labeled with "figures of elevation." To further accentuate the terrain, a gradient system of coloring is also employed. The lighter colors being used to show lower areas with a gradual increase in density/darkness to portray the higher terrain.

Military operations require the analysis of contour-labeled charts to visualize the land. In operational planning this is of the utmost importance, whether it is planning a route for a safe flight or in determining the best escape route from enemy territory.

On charts of poorly known areas, mountains may be indicated by hachures or shading lines, with the elevations of peaks given as accurately as they are known. Hachures may be used on charts to show prominent hills or buttes too small to show up otherwise because of the large contour interval.

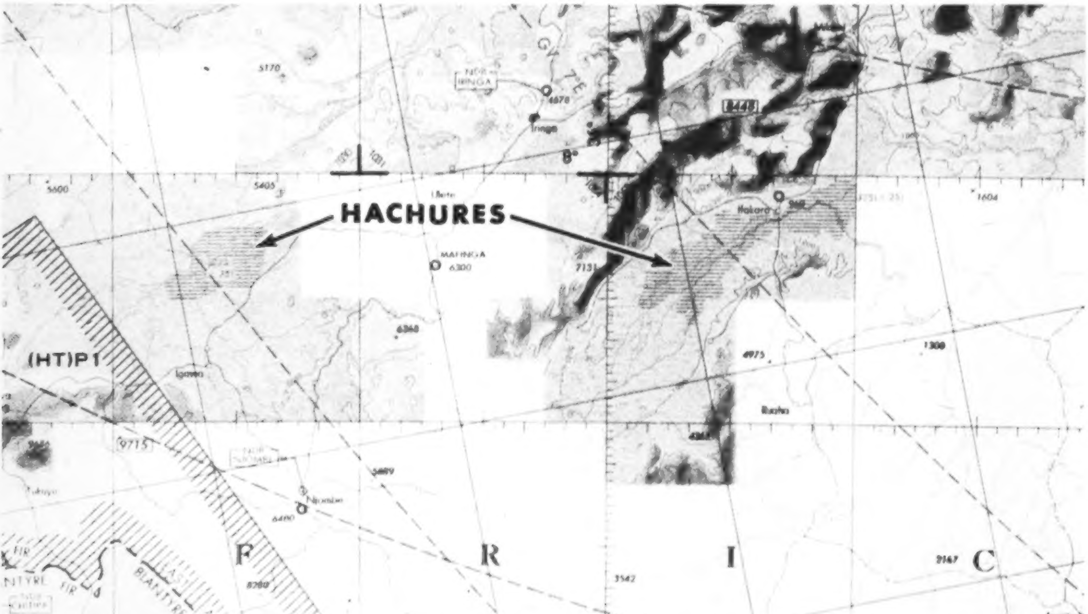

HACHURES
RELIEF
DATA INCOMPLETE
(HT)P1
(HT)P1
F
R
I
C
8°
10°
12°
36°
MAFINGA
Iringa
Nyamtumbo
BEIRA
AFRICA
MALAWI
MZUZU
Tunduru
TENENTE VALADIM

Figure 7-8. Use of Hachures on Contour Map

CHAPTER 8

Practical Application of DR and Map Reading (Sample Navigation Mission)

Previous chapters have been devoted to various parts of basic navigation—maps and charts, plotting equipment, DR computer and the wind triangle. Standing alone, these parts have little practical value; when used in combination, they form the basis of all navigation, Dead Reckoning. This chapter is devoted to combining these parts of DR and also shows the use of map reading as an aid to DR. To illustrate the procedures, a cruise portion of a sample navigation mission is used. Only the cruise portions are covered since procedures related to mission planning, takeoff, and climb are explained in detail in later chapters.

FLIGHT PLANNING

For the sample mission, departure has been selected at coordinates 29-58N, 94-13W with destination at 31-36 1/2N, 84-06W. The mission is planned for a cruising altitude of 9,000 feet with a true airspeed of 220 knots. In planning the mission, the navigator first checks with the weather forecaster and finds he can expect stratus and cumulus clouds with bases at 4,000 feet and tops generally at 8,000 feet. Isolated thunderstorms are reported about halfway to destination, with conditions becoming scattered to clear during the last half of the mission.

Winds obtained are as follows:

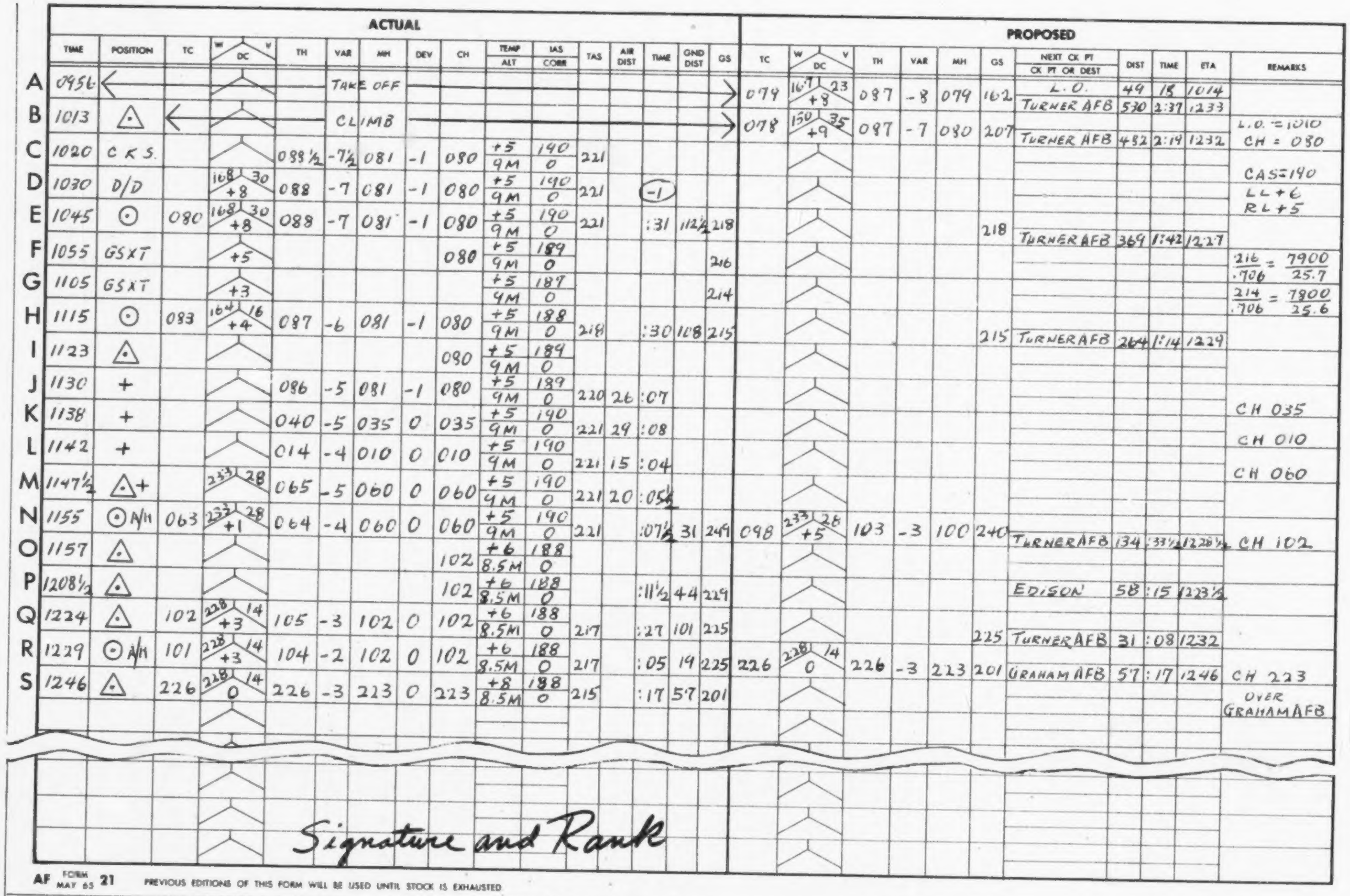
Altitude in Feet	*Departure W/V*	*Temperature in °C*	*Destination W/V*
8,000	150/35	+11	230/30
10,000	150/35	+ 6	210/30
12,000	130/45	+ 2	210/35

The navigator is using an ONC chart for this mission since the primary aid to DR is Map reading. Departure and destination are plotted and the true course drawn between them. The navigator measures the true course and finds it to be 079°. Since this is a single leg mission only one true course is required. On a mission with several legs, each turning point and each course line would be constructed. In flight planning, the length of a leg or the operational conditions also dictate whether the navigator uses an average wind between departure and destination, or uses predicted metro winds for segments of each leg. The same holds true for variation when flight planning. On a long navigation leg, use of average variation causes the aircraft to swing off course, although it does have the advantage of not requiring frequent heading changes.

This mission is relatively short, lending itself to use of average winds and variation. However, the navigator wishes to stay as close as possible to true course, therefore he plans his initial heading using metro winds and variation at departure. He further determines flight plan distance to be 530 nautical miles and desired indicated airspeed for flight altitude to be 190 knots.

INFLIGHT PROCEDURES

Takeoff is accomplished at 0956 hours. Using a standard departure from the field, an on-course climb to flight level is begun. The navigator records T.O. time in the ACTUAL portion of AF Form 21, Navigator's Log, and ETA in the PROPOSED section as shown in figure 8-1, line



	ACTUAL																				PROPOSED												
	TIME	POSITION	TC	W	V	DC	TH	VAR	MH	DEV	CH	TEMP	ALT	IAS	CORR	TAS	AIR DIST	TIME	GND DIST	GS	TC	W	V	DC	TH	VAR	MH	GS	NEXT CK PT CK PT OR DEST	DIST	TIME	ETA	REMARKS
A	0956	←						TAKE OFF												→	079	167	23	+8	087	-8	079	162	L.O. TURNER AFB	49 530	18 2:37	1014 1233	
B	1013	◬	←					CLIMB												→	078	150	35	+9	087	-7	080	207	TURNER AFB	482	2:14	1232	L.O. = 1010 CH = 080
C	1020	C K S.					088½	-7½	081	-1	080	+5	9M	190	0	221																	
D	1030	D/D		168	30	+8	088	-7	081	-1	080	+5	9M	190	0	221		-1															CAS=190
E	1045	⊙	080	168	30	+8	088	-7	081	-1	080	+5	9M	190	0	221		:31	112½	218								218	TURNER AFB	369	1:42	1227	LL+6 RL+5
F	1055	GSXT				+5					080	+5	9M	189	0					216													$\frac{216}{.706} = \frac{7900}{25.7}$
G	1105	GSXT				+3						+5	4M	187	0					214													$\frac{214}{.706} = \frac{7800}{25.6}$
H	1115	⊙	083	164	16	+4	087	-6	081	-1	080	+5	9M	188	0	218		:30	108	215								215	TURNER AFB	264	1:14	1229	
I	1123	◬									090	+5	9M	189	0																		
J	1130	+					086	-5	081	-1	080	+5	9M	189	0	220	26	:07															
K	1138	+					040	-5	035	0	035	+5	9M	190	0	221	29	:08															CH 035
L	1142	+					014	-4	010	0	010	+5	9M	190	0	221	15	:04															CH 010
M	1147½	◬+		233	28		065	-5	060	0	060	+5	4M	190	0	221	20	:05½															CH 060
N	1155	⊙ A/H	063	233	28	+1	064	-4	060	0	060	+5	9M	190	0	221		:07½	31	249	098	233	28	+5	103	-3	100	240	TURNER AFB	134	:33½	1228½	CH 102
O	1157	◬									102	+6	8.5M	188	0																		
P	1208½	◬									102	+6	8.5M	188	0			:11½	44	229									EDISON	58	:15	1223½	
Q	1224	◬	102	228	14	+3	105	-3	102	0	102	+6	8.5M	188	0	217		:27	101	225								225	TURNER AFB	31	:08	1232	
R	1229	⊙ A/H	101	228	14	+3	104	-2	102	0	102	+6	8.5M	188	0	217		:05	19	225	226	228	14	0	226	-3	223	201	GRAHAM AFB	57	:17	1246	CH 223
S	1246	◬	226	228	14	0	226	-3	223	0	223	+8	8.5M	188	0	215		:17	57	201													OVER GRAHAM AFB

Signature and Rank

AF FORM MAY 65 21 PREVIOUS EDITIONS OF THIS FORM WILL BE USED UNTIL STOCK IS EXHAUSTED

Figure 8-1. Sample Mission, Navigator's Log

A. At 1010 hours the aircraft reaches flight altitude and leveloff is accomplished. At this time the navigator reads the compass at 080°, leveloff time and compass heading are then recorded in the PROPOSED section of the navigator's log under REMARKS. Since the navigator wishes to establish his position as soon as possible after leveloff, he obtains and plots a map reading fix for 1013 hrs (figure 8-2). This fix is recorded in the ACTUAL section of the log for the time of 1013 (figure 8-1, line B). Since the fix shows the aircraft to be on course, the navigator then computes his distance to destination from the fix. Using preflight wind and groundspeed he finds the ETA to be 1232.

Instrument Entries

From this point on, the frequency of instrument readings or averages of readings is dependent upon navigation methods, mission conditions, unit procedures, or personal preference. If instrument readings remain fairly constant then fewer entries are needed.

Deviation Check

The principle of and reasons for compass deviation are explained in Chapter 4, and the methods of obtaining this deviation are fully explained in Chapter 15. For purposes of this mission it will suffice to say that the navigator obtains a true heading (TH) with a periscopic sextant, applies spot variation to obtain magnetic heading (MH), and then compares the MH to the compass heading (CH), which is taken at the same time as the true heading (TH). On this mission the navigator takes a deviation check at 1020 and determines compass deviation to be —1°. At the same time he computes pertinent airspeed information and records all readings as shown in figure 8-1, line C.

There is no set rule to guide the navigator in taking deviation checks, however, a general rule to follow is to obtain an initial deviation check, and an additional one each time the compass heading changes by more than 15°.

DR Positions

Positioning of the aircraft enroute is a continuous process. Frequency of positioning information depends primarily on flight conditions and types of fixing aids available to the navigator. The following general rules of frequency may be applied:

- Every half hour, if there is no significant change in flight conditions.
- Whenever heading is altered, either at a predetermined point or for some other reason.

Significant changes in flight conditions may be defined as a wind shift that would alter drift more

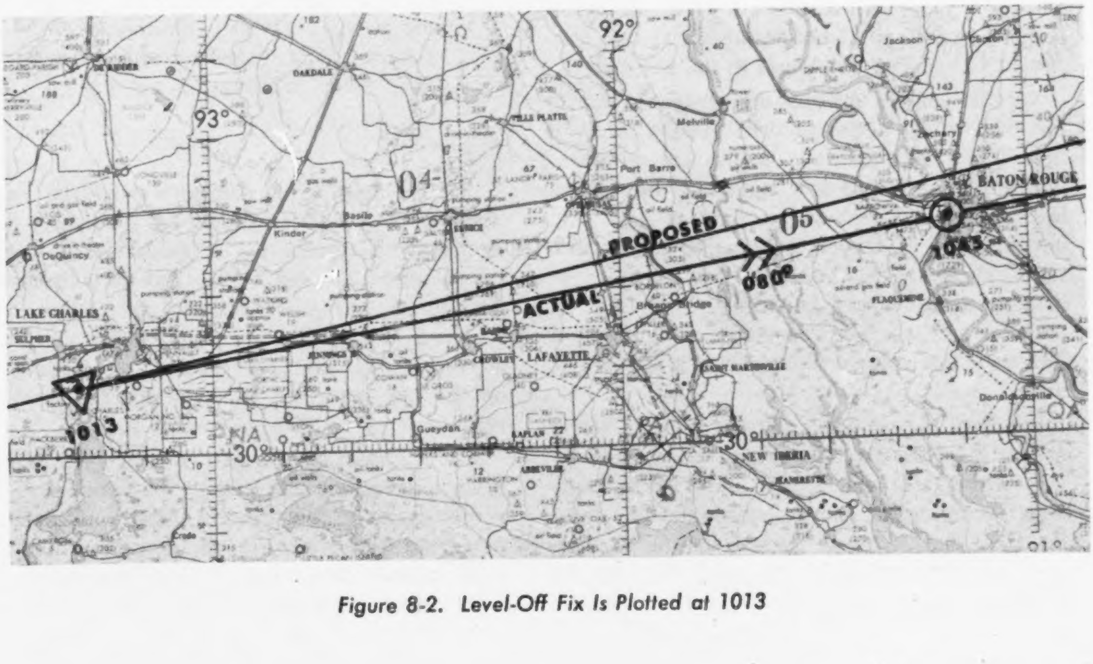


Figure 8-2. Level-Off Fix Is Plotted at 1013

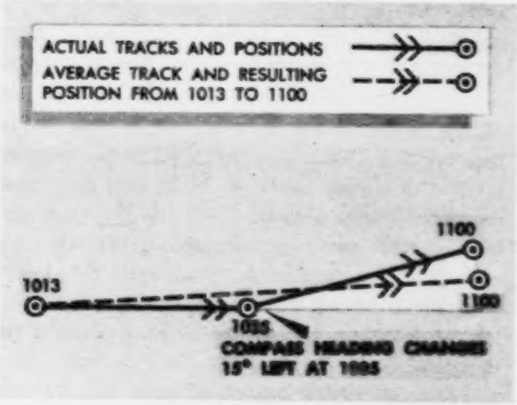

ACTUAL TRACKS AND POSITIONS
AVERAGE TRACK AND RESULTING POSITION FROM 1013 TO 1100
1013
1035
1100
1100
COMPASS HEADING CHANGES 15° LEFT AT 1035

Figure 8-3. Inaccuracy Caused by Use of Average Heading

than 3°, a change in airspeed of more than 10 knots, or a change in CH of more than 8°. To allow too much of a change in flight conditions without obtaining a position causes navigation inaccuracies if the navigator attempts to average out the changes at a later time. Figure 8-3 illustrates an exaggerated form of the inaccuracy caused by use of average heading.

Determination of Wind and Groundspeed

Double drifts or groundspeeds by timing with a driftmeter are primarily applicable to training situations; however, they are a basic procedure for determining wind and groundspeed and thus should be familiar techniques to the navigator.

On the sample mission the navigator directs the pilot to fly a double drift (D/D) at 1030 hours. He has previously determined on-course drift to be +8°, and now reads drift on the left leg as +6° and drift on the right as +5°. He has now logged enough information to compute the wind (figure 8-1, line D). This includes true heading, true airspeed and drift on all legs. In addition, he has logged one minute of lost forward motion to compensate for time lost in the double drift.

At 1045 the navigator obtains a DR position (figure 8-1, line E). To obtain this position he applies the D/D wind to TH and TAS to determine average track and groundspeed (GS) from the 1013 fix. Although elapsed time is 32 minutes, forward motion is computed for only 31 minutes, since 1 minute is subtracted for the time lost in the D/D. The track and distance plotted in figure 8-2 are 080° and 112½ NM. From the DR position the navigator measures distance to destination and using the D/D wind and groundspeed computes a new ETA.

Groundspeed by Timing

The navigator obtains two groundspeeds by timing at 1055 and 1105. Together with drift and instrument readings this information is logged as illustrated in figure 8-1, lines F and G. Using the formula for groundspeed by timing the average of the two groundspeeds is determined to be 215 knots.

At 1115 he computes his second DR position (figure 8-1, line H). This position is based upon 30 minutes elapsed time (1045-1115), at a groundspeed of 215 knots. At this time he also computes a new ETA to destination. Plotting of the 1115 position is shown in figure 8-4.

At this time the navigator notes that isolated thunderstorms lie across the heading of the aircraft. Since his DR indicates that the aircraft is to the right of course, he notifies the pilot that heading alterations to circumnavigate the thunderstorms should be made to the left. Because it is probable that numerous heading alterations will be required to circumnavigate the weather, he also desires to secure a map reading fix from which to start airplot.

At 1123 the navigator locates his position as illustrated in figure 8-5. Fix information consisting of time, fix symbol, and instrument readings, is logged as shown in figure 8-1, line I.

Airplot

The problem of the navigator would be very simple if he could plot the ground position of the aircraft with respect to its movement through the air mass (TH and TAS). But the movement through the air mass (wind) complicates the problem. Previously, the wind vector and the air vector (TH and TAS) have been combined on the DR computer to determine the ground vector (Track and GS) for a DR position.

Under certain conditions it is faster and easier to solve navigation problems by the use of airplot. Airplot is the graphic solution of the wind triangle on a chart or computer for the purpose of finding a DR position or a wind. It must be understood that airplot is not a different method of navigation,

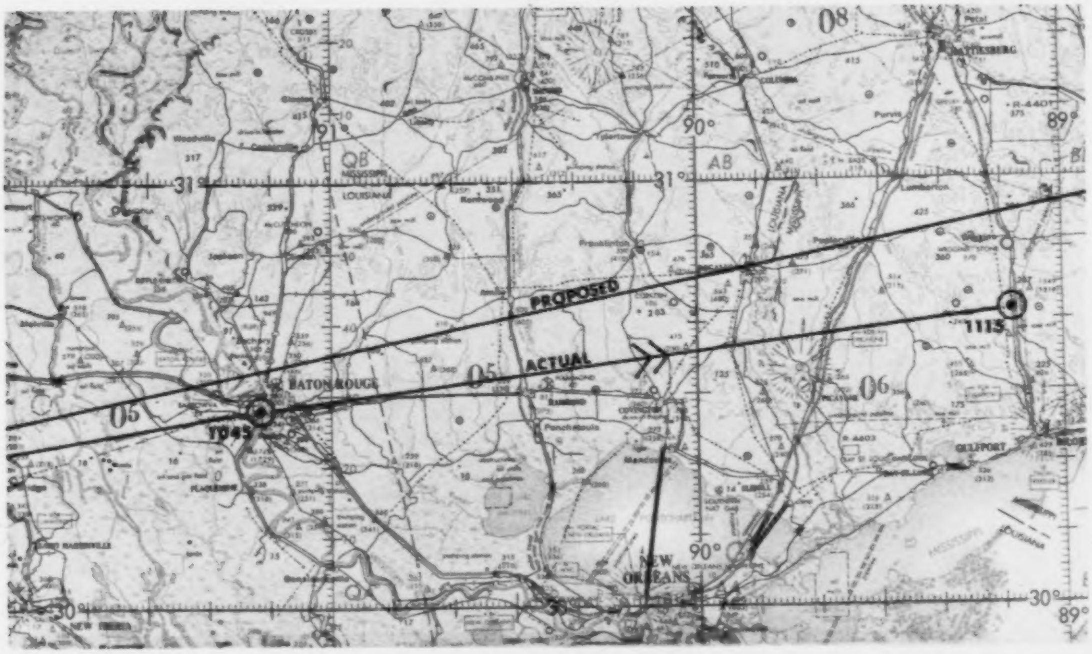

PROPOSED
ACTUAL
1045
1115
BATON ROUGE
NEW ORLEANS
90°
31°
30°
89°
05
06
08
QB
AB
GULFPORT

Figure 8-4. Plotting 1115 DR Position

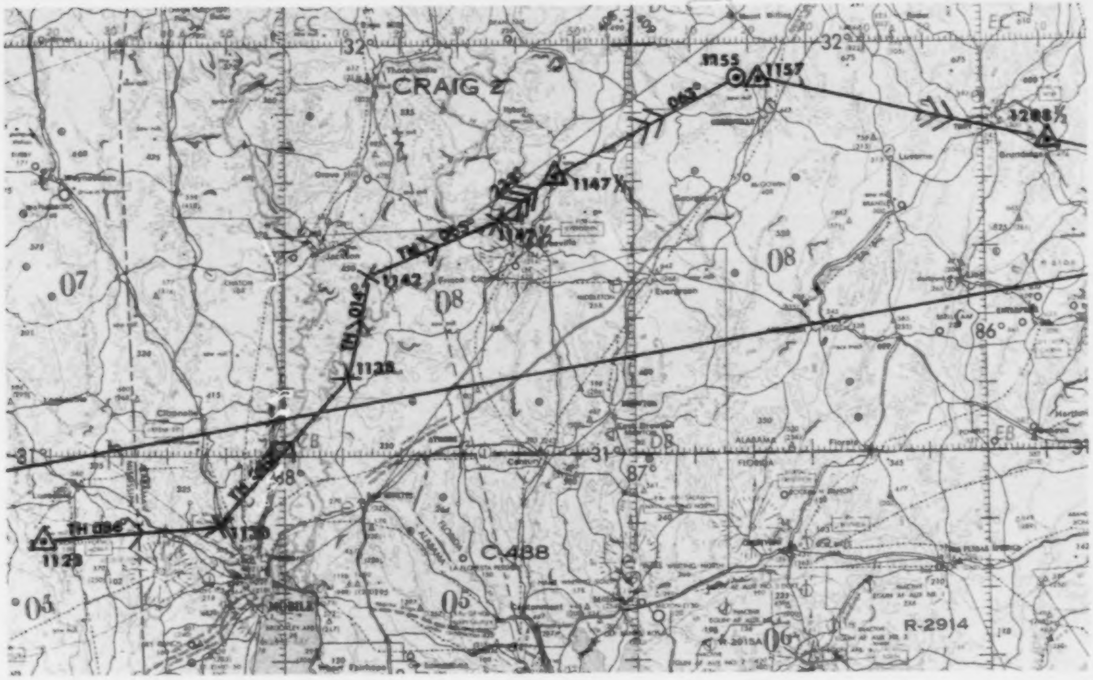

CRAIG 2
1123
TH 096
1130
1135
1142
1147
1155
1157
1208
062°
C-488
R-2914
MOBILE
07
08
05
06
31°
32°
87°
86°
CC
CB
DB
EB

Figure 8-5. Airplot Is Started at 1123 Fix

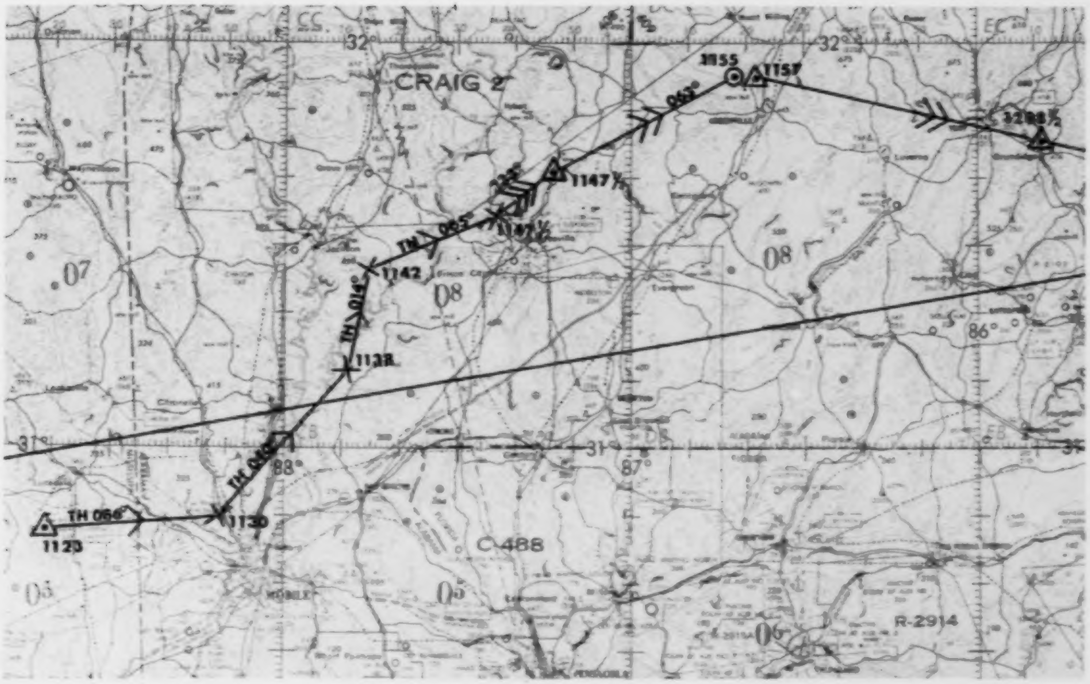

CRAIG 2
32°
1155
1157
063°
1147½
TH 065°
1142
TH 014°
1138
31°
TH 040°
88°
87°
86°
TH 066°
1123
1130
C-488
R-2914
08
07
05
06

Figure 8-5. Airplot Is Started at 1123 Fix (repeated)

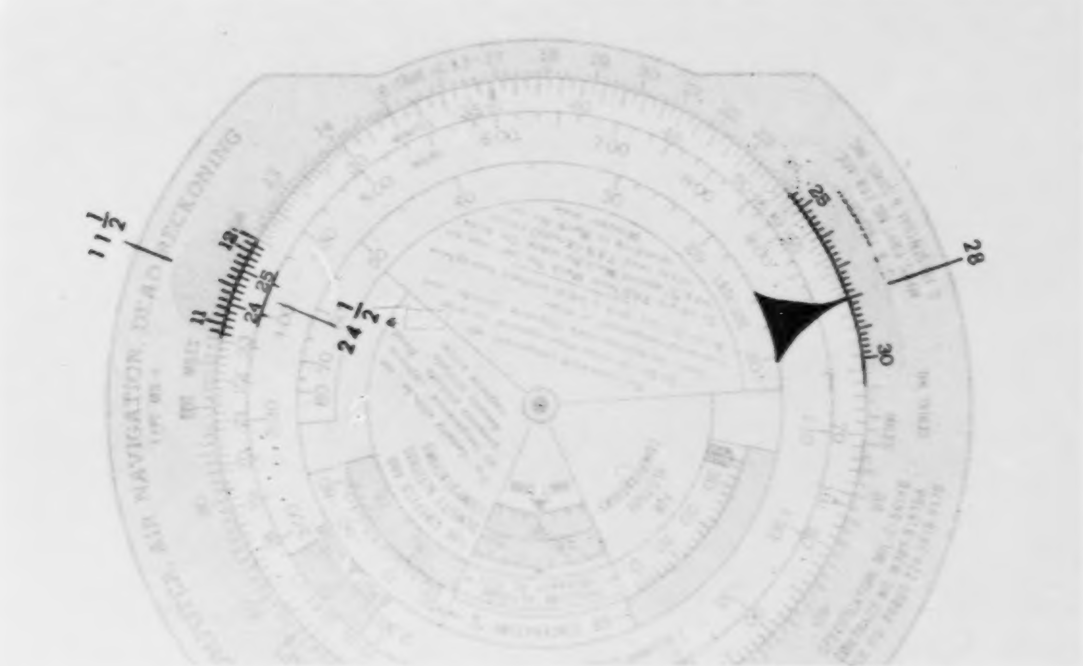

11½
24½
28
25
30
AIR NAVIGATION DEAD RECKONING

Figure 8-6. Wind Speed Is 28 Knots

but merely a difference in the application of the vectors of the wind triangle.

Airplot becomes useful when the heading of the aircraft changes radically and frequently. It then becomes much easier to follow the movement of the aircraft through the air mass using TH and TAS than computing a DR position each time the heading changes.

Obviously, airplot must be done quickly and accurately so it may be completed with an accurate DR position from which the heading to destination can be resumed. The basic reason that airplot is faster than groundplot is that wind effect is not considered until all heading changes have been completed. At that time the net wind effect for the period of airplot is applied to the final air position to determine a ground position.

Airplot on Chart. To be accurate, airplot must be started at a known position—in this case the 1123 fix as illustrated in figure 8-5. The navigator had previously decided he would begin airplot at his first fix after the 1115 DR position. The movement of the aircraft is represented on the chart by a series of vectors based on TH and TAS.

At 1130 the pilot alters heading to 035° to circumnavigate weather. Thus the first air vector is found using TH and TAS for seven minutes (1123-1130). The information is logged as illustrated in figure 8-1, line J. An examination of this line entry reveals that the navigator is recording only the minimum amount of information necessary to compute the air vector. Extensive logwork is time consuming and is one reason why airplot is faster than groundplot.

At 220 knots (TAS) the aircraft has travelled 25 air miles in seven minutes. The air vector is plotted on a TH of 086° as shown in figure 8-5.

At 1138 the aircraft changes compass heading to 010°. Again the navigator plots the air vector. He finds that he has travelled 29 air miles (1130-1138) on a true heading of 040°. Each time an air position is completed, the navigator uses a plus sign indicating the air position, and connects the two air positions with a line labeled with a single arrow for an air vector.

At 1142 the pilot alters the aircraft compass heading to 060°. The navigator plots the completed air vector of 15 air miles on a TH of 014° (1138-1142). Since the new heading will safely circumnavigate the weather, the navigator begins procedures to obtain a map reading fix from which he can compute a heading to destination.

Establishing Position. After a period of airplot two methods are commonly used to establish aircraft position. The first method is to use the last known wind and plot a proportionate amount of this wind using the amount of time spent in airplot. The wind vector is plotted from the last air position with the tail of the vector representing air positions; the head of the vector will then be the ground position for that time.

The second method is to simply use the last air position as a starting point. This method is usually satisfactory only if the time spent in airplot is short and the wind speed is light. In the case of high winds the air position can be considerably in error from the actual ground position.

At 1147½ the navigator obtains a map reading fix over a small railroad bridge, as shown in figure 8-5. An air position is plotted for the same time. The air vector will be 20 air miles on a TH of 065° (1142-1147½). The fix and air position are logged on the same line as shown in figure 8-1, line M. The vector between these two positions represents net wind effect for the time spent in airplot. When converted to an hourly increment, it provides wind speed and direction.

To obtain an airplot wind, the navigator measures the direction of the wind vector, remembering that the wind always blows from the air position to the ground position. The direction of the vector as measured on the chart is 233° (labeled with 3 arrows representing wind) as shown in figure 8-5. The length of the vector represents the wind effect on the aircraft from the time airplot was started till the time it is completed. The navigator finds this vector to be 11½ nautical miles long which represents the wind effect for 24½ minutes (1123-1147½). These two figures are then set on the slide rule side of the DR computer and the speed of the wind is read over the 60 minute index. The proportion for this particular problem provides an answer of 28 knots as shown in figure 8-6.

Airplot on Wind Side of Computer. Plotting air vectors on the grid of the computer and obtaining a resultant air vector is exactly the same as the method used in obtaining a vector average of winds.

When plotting air vectors on the grid of the

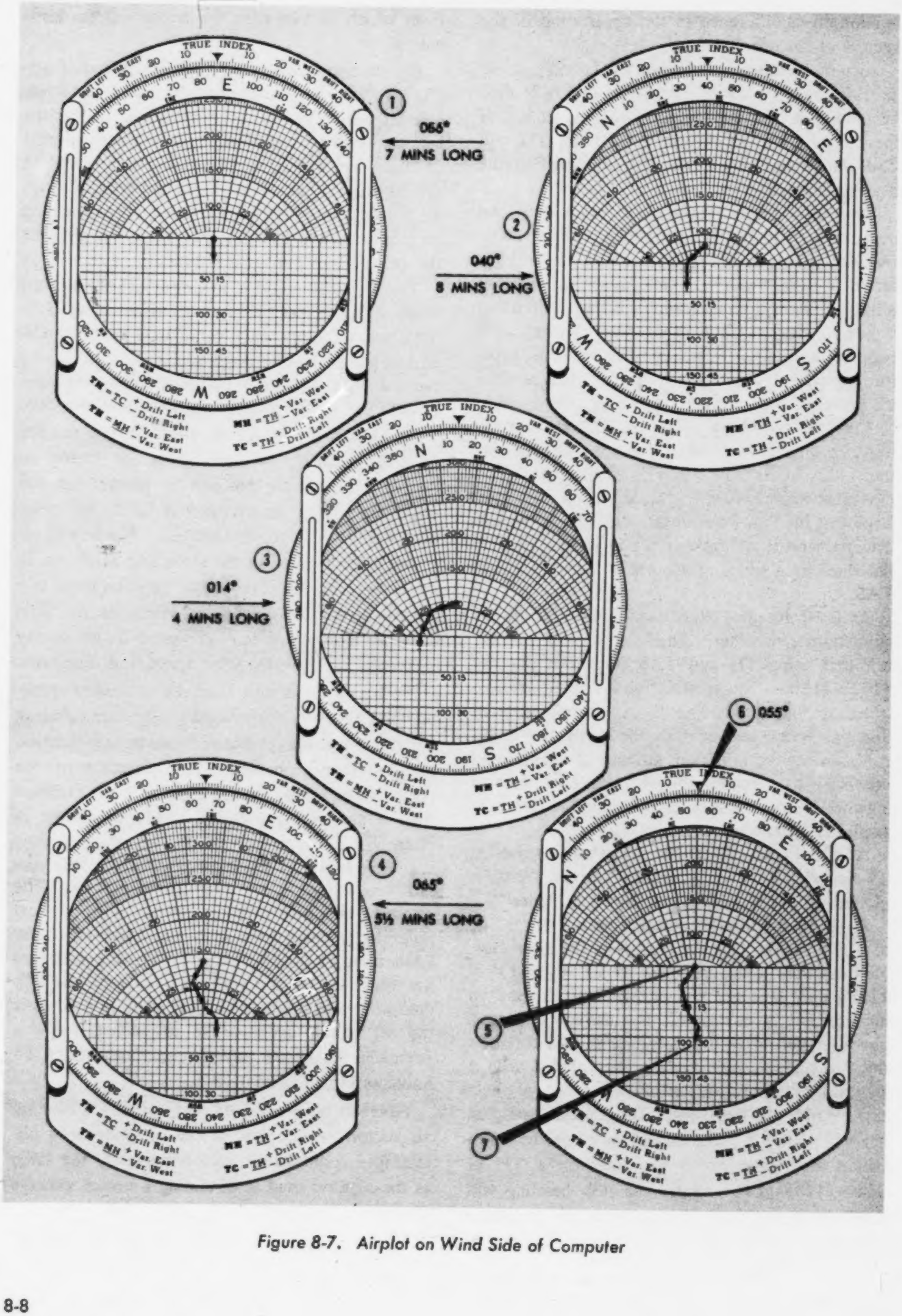

①
056°
7 MINS LONG
②
040°
8 MINS LONG
③
014°
4 MINS LONG
④
065°
5½ MINS LONG
⑥ 055°
⑤
⑦
TRUE INDEX
DRIFT LEFT VAR EAST
VAR WEST DRIFT RIGHT
TH = TC + Drift Left − Drift Right
TH = MH + Var. East − Var. West
MH = TH + Var. West − Var. East
TC = TH + Drift Right − Drift Left

Figure 8-7. Airplot on Wind Side of Computer

computer, the navigator will find that he must usually halve the air miles to get them all on the computer. This increases the change for errors, therefore, an easier and quicker way has been devised. Instead of plotting air miles, the navigator plots minutes; in other words, time is plotted as the magnitude of the vector. Using this method shown in figure 8-7, the airplot problem for this mission would be solved as follows·

1. Using the grid side of the wind slide, set the first TH (086°) under the computer index. Draw down from the grommet a vector of seven representing minutes on the first heading (1123-1130). Each horizontal grid line represents 2 minutes.

2. Set the second TH (040°) under the index. Adjust the slide so that the head of the first vector is on the zero grid line. Draw down, from the head of the first vector, a second line representing 8 minutes on the second heading (1130-1138).

3. Set the third TH (014°) under the index. Adjust the slide so that the head of the second vector is on the zero grid line and draw the third vector for four minutes (1138-1142).

4. Set the fourth and last TH (065°) under the index, adjust the slide so the head of the third vector is on the zero grid line. Draw a vector down from the head of the third vector for five and one-half minutes which represents the time on the fourth heading (1142-1147½).

5. Set the slide so that the grommet is again on the zero grid line.

6. Turn the compass rose so the head of the fourth and last vector is on the center line directly below the grommet. The direction under the index (055°) is the resultant TH for the entire time of the problem.

7. Count the total minutes from the grommet to the head of the last vector. This time (22 minutes) is then set up on the slide rule side of the computer with average TAS during the entire period of airplot to obtain the air miles for the length of the resultant air vector. At an average TAS of 221 knots for the 22 minutes, the aircraft traveled 81 nautical miles. Remember, even though airplot was conducted for 24½ minutes, the resultant is for 22 minutes.

If extremely frequent heading changes and short periods of time are anticipated or encountered, the navigator would be wise to use the computer to follow the aircraft by airplot. It is faster and, if care is taken in plotting the vectors, the computer method is nearly as accurate as plotting the individual vectors on the chart. Theoretically either method will yield the same results, but the small scale of the computer grid prevents equal accuracy. For example, on the sample mission it is found that the resultant air vector of 055° and 81 air miles would give an air position approximately one-half mile away from the one determined by conventional plotting methods.

ALTER HEADING TO DESTINATION. The navigator decides he will alter to destination at 1155. With the information obtained from the 1147½ fix, he obtains a DR position for 1155. By assuming that the aircraft would stay on the same heading and airspeed until that time, the navigator can compute a track and groundspeed using the airplot wind obtained at 1147½. He computes a distance of 31 nautical miles for seven and one-half minutes on a predicted tract of 063° (1147½-1155). He logs this information as shown in figure 8-1, line N.

The computation of a new MH and an estimated time of arrival (ETA) to destination (Turner AFB) from the 1155 DR position is very similar to a preflight problem. The navigator measures the new true course and distance between the two positions and logs it in the proposed portion of the log as shown in figure 8-1, line N. Again assuming an indicated airspeed of 190 knots, altitude of 9000 feet, and temperature of +5°, he computes a TAS of 221 knots. With the latest wind (the airplot wind) he can compute a predicted drift correction (DC) and groundspeed, and work from TC to MH by applying the DC and variation to obtain an MH to fly. The ETA again is computed using the latest airplot wind.

Map Reading as an Aid to DR

At 1157, two minutes after the alter heading, the navigator obtains a fix over a bend in the road (figure 8-5). This information is logged as shown in figure 8-1, line O. At 1208½ another fix is obtained on a railroad 2 nautical miles north of Brundidge (see figure 8-8). The navigator computes a GS from the 1157 fix, and an ETA to a new check point at Edison for 1223½ (figure 8-1, line P).

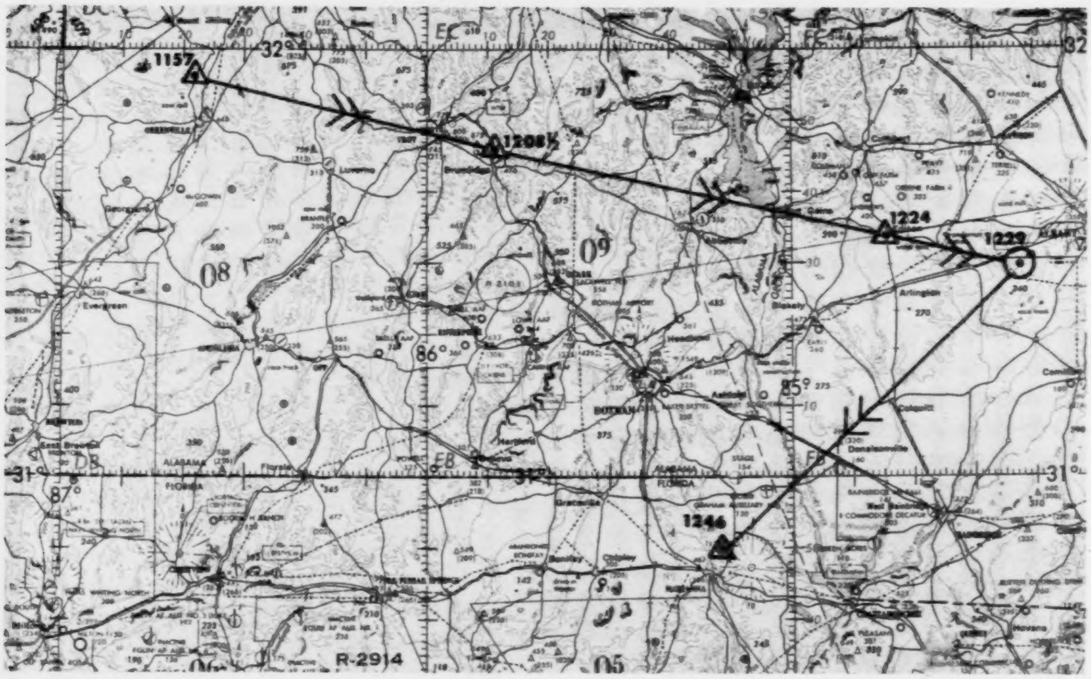


Figure 8-8. Alter Heading at 1229

At 1224 the aircraft is directly over Edison (figure 8-8). At this time the pilot informs the navigator that Air Traffic Control is diverting the aircraft to a new destination (Graham Air Field). The navigator decides to alter heading to the new destination at 1229. He computes a DR position for this time (figure 8-8). Working ahead, he logs information pertinent to this position as shown in figure 8-1, line R. All information necessary to alter heading to the new destination is computed and logged, to include course, heading, groundspeed, and ETA. At 1229 heading is altered to the new destination.

In this sample problem no log and chart entries have been made between 1229 and 1246. However, in actual practice the navigator would continue to record instrument readings and obtain fixes as necessary to direct the aircraft into destination.

SUMMARY

There are many procedures and many means of using dead reckoning and map reading techniques. However, throughout the Air Force, navigators use the same terminology and the same standard log and chart symbols. A log and chart should contain enough accurate entries to fully reconstruct a mission. Good discipline in keeping an adequate log and chart contributes to the overall efficiency of every navigator and aids in successful mission completion.

CHAPTER 9

Radio

The first airborne radio was used to enable the pilot to keep informed of weather along his flight path. The gradual development of directional radio equipment made possible a system of radio routes (beams) which eventually formed aerial highways. World War II fostered the development of several new radio aids, the most important of which were loran and radar.

World War II also fostered the principle of another radio aid to navigation called Consol. This principle originated with the Germans and was improved by the British in post war years. The United States version is called Consolan.

The rapid growth of air traffic following World War II necessitated improved radio aids for instrument navigation and traffic control. Some of the aids developed were the VOR system, TACAN, IFF/SIF, and improved communications equipment.

The terms VOR, TACAN, Consol, Consolan, and IFF/SIF are explained and discussed in this chapter.

FUNDAMENTALS

Frequency Classification

Energy in the frequency range of 20 to 20,000 hertz (Hz) is capable of carrying audible communications. This frequency range is called the audio-frequency (AF) band.

NOTE: The National Bureau of Standards has adopted a hertz (Hz) as the Standard Unit Notation for measures of frequency. Thus, 60 cycles per second has become 60 Hz Units, 400 CPS has become 400 Hz units, and so on. The name is in honor of Heinrich Rudolph Hertz, discoverer of electromagnetic waves.

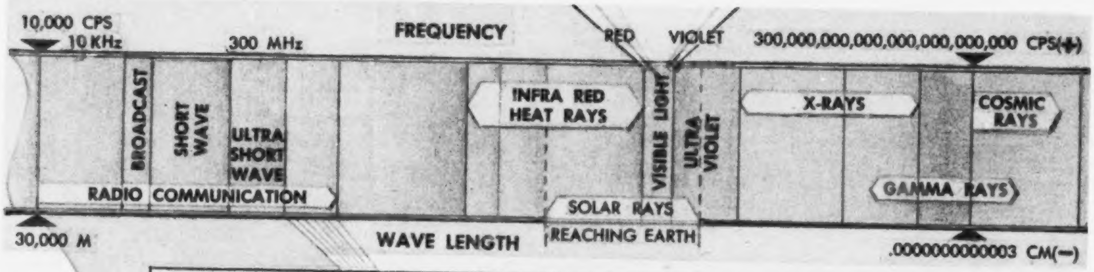
The range of frequencies used in radio communication is called the *radio spectrum.* Radio frequencies extend from approximately 10 kHz to 300,000 mHz and have been arbitrarily divided into bands. See figure 9-1.

Properties

Radio waves, like light waves, undergo reflection, refraction, diffraction, and absorption, and become attenuated (reduced in amplitude) as they travel from the source of radiation. See figure 9-2.

REFLECTION. Reflection is the sharp change in the direction of travel of an incident wave which occurs at the surface of a medium. The waves "bounce" from the reflecting surface. A common example of this is the reflection of a beam of light from a mirror. All types of waves can be reflected under certain conditions. Radio waves are no exception. When reflection occurs, the angle of incidence is exactly equal to the angle of reflection.

REFRACTION. Electromagnetic energy emitted from a hypothetical "point" source (an antenna) near the surface of the earth would travel in all directions horizontally and vertically in a series of ever-expanding, concentric spheres. A small portion of one of these spheres is termed a *wave front.* At a considerable distance from the antenna, the spherical nature of the wave front is less evident and it appears as a plane at right angles to the direction of energy propagation. Refraction is the bending of wave fronts as they pass obliquely from one medium to another or through a medium of varying density. The refraction, or bending, is caused by a difference in the speed of the waves through two mediums. The mediums through which radio waves travel are


10,000 CPS
10 KHz
300 MHz
FREQUENCY
RED
VIOLET
300,000,000,000,000,000,000,000 CPS(+)
BROADCAST
SHORT WAVE
ULTRA SHORT WAVE
RADIO COMMUNICATION
INFRA RED HEAT RAYS
VISIBLE LIGHT
ULTRA VIOLET
X-RAYS
COSMIC RAYS
GAMMA RAYS
SOLAR RAYS
REACHING EARTH
30,000 M
WAVE LENGTH
.0000000000003 CM(−)

BAND	ABBRE-VIATION	Frequency range	WAVE LENGTH	
			Longest	Shortest
AUDIO	AF	0.02 to 20KHz	∞	20,000 m
RADIO				
Very low frequency	VLF	Below 30 KHz	30,000 m	10,000 m
Low frequency	LF	30 to 300KHz	10,000 m	1,000 m
Medium frequency	MF	300 to 3,000KHz	1,000 m	100 m
High frequency	HF	3,000 to 30,000KHz	100 m	10 m
Very high frequency	VHF	30 to 300MHz	10 m	1 m
Ultra high frequency	UHF	300 to 3,000MHz	100 cm	10 cm
Super high frequency	SHF	3,000 to 30,000MHz	10 cm	1 cm
Extremely high frequency	EHF	30,000 to 300,000MHz	1 cm	0.1 cm
HEAT AND INFRARED		3×10^{11} to 3.6×10^{14} Hz	10^{-1} cm	8.3×10^{-5} cm
VISIBLE SPECTRUM		3.6×10^{14} to 7.8×10^{14} Hz	8.3×10^{-5} cm	3.8×10^{-5} cm
ULTRAVIOLET		7.8×10^{14} to 2.4×10^{16} Hz	3.8×10^{-5} cm	1.2×10^{-6} cm
X-RAYS		6×10^{15} to 5×10^{19} Hz	5×10^{-6} cm	6×10^{-10} cm
GAMMA RAYS		6×10^{18} to 6×10^{20} Hz	5×10^{-9} cm	5×10^{-11} cm
COSMIC RAYS		3×10^{20} to 10^{23} Hz (+)	10^{-10} cm	shorter than 3×10^{-13} cm

Figure 9-1. Electromagnetic Spectrum

the various strata or layers of ionized gases which surround the earth called the ionosphere.

DIFFRACTION. Diffraction of electromagnetic energy occurs when energy travels near the edge of solid objects through which it cannot pass. Again, the concept of the wave front may be used to explain the process.

ABSORPTION. Absorption is the loss of radio energy within a medium resulting from its conversion into heat. Radiated energy is absorbed by objects on the surface of the earth, such as trees and buildings, and by the earth itself. The radiated energy is said to be attenuated as it passes through a medium.

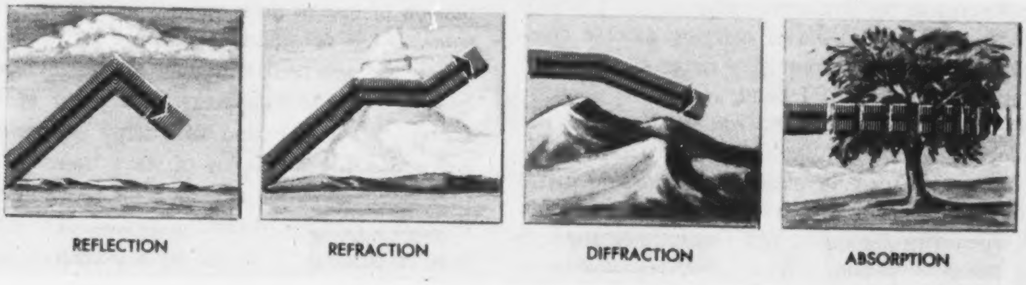

REFLECTION
REFRACTION
DIFFRACTION
ABSORPTION

Figure 9-2. Properties of Radio Waves

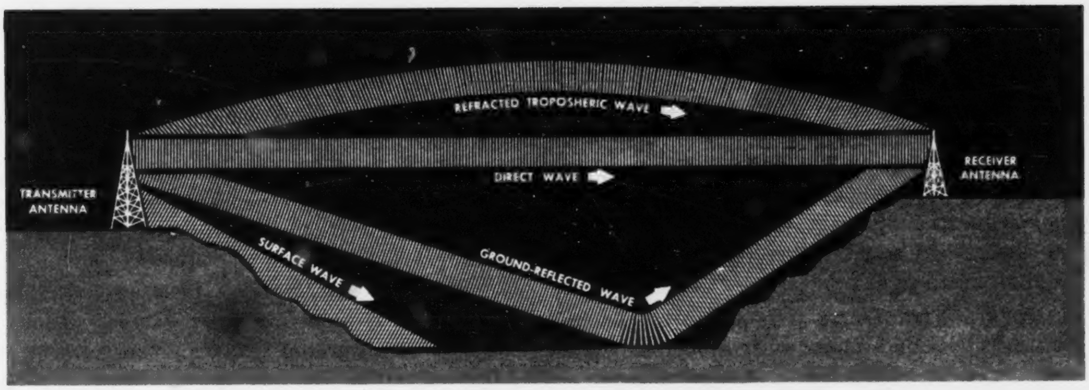


Figure 9-3. Ground Waves, Sky Waves, and Direct Waves

Electromagnetic Propagation

Behavior of Radio Waves. Radio waves are generally classified as ground waves, sky waves, or direct waves according to the path along which they travel to the receiver (figure 9-3).

Ground Waves. Radiated energy which follows the surface of the earth is called the ground wave. Transmission frequency and transmitter power determine the distance a ground wave can be used for reliable reception. Ground wave signals in the low and medium frequency bands can be received reliably at distances of several hundred miles. As transmission frequency increases, ground wave coverage decreases rapidly. At VHF and higher frequencies, ground wave coverage is limited to only a few miles.

Sky Waves. Sky waves are radio waves which are refracted by the earth's atmosphere. Radio communication between distant points on the earth depends principally upon sky waves.

As frequency is increased from the LF band through the HF band, skip distance becomes greater and greater until the VHF band is reached. Although VHF skip signals are not uncommon, in most instances ionospheric refraction is not sufficient to return these signals to earth. UHF and higher frequencies are refracted to an even lesser degree than VHF.

Whether or not a given wave returns to the earth depends upon the degree of ionization, wave radiation angle, and the transmission frequency of the signal.

Direct Waves. Radio energy which follows a line-of-sight path between a transmitter and a receiver is called a direct wave. Normal air-to-ground communications in the VHF, UHF, and higher bands rely on the use of direct waves.

Skip Distance. For a given frequency, there is a minimum distance from the transmitting antenna within which sky waves are not received. This

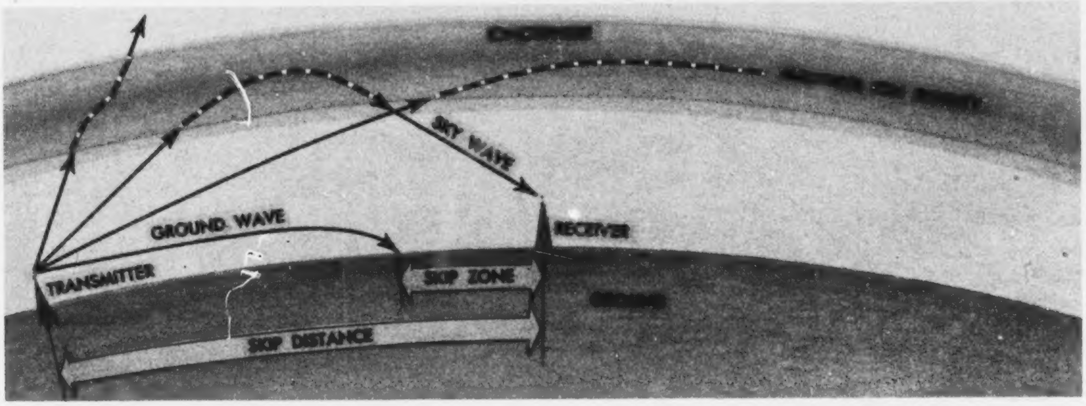


Figure 9-4. Skip Distance and Skip Zone

minimum distance is called skip distance. When the distance covered by ground waves is less than the skip distance, a *skip zone* occurs between the outer limit of the ground waves and the first sky wave. Skip distance and skip zone are illustrated in figure 9-4.

OTHER CONSIDERATIONS. Since radio waves are influenced by many variables, it is essential to understand several other factors which affect a transmitted signal.

Night Effect. There is a period of the time during sunset and sunrise when ground waves and sky waves overlap because of rapid changes occurring in the ionosphere. This is known as polarization error or night effect, and causes difficulty in matching the correct signals.

Fading. Fading occurs when a single transmission of radio energy arrives at a receiver as both a ground wave and a sky wave, or as two different sky waves. If the two waves arrive in phase, they reinforce each other, resulting in a stronger signal. If they arrive in opposite phase, however, they tend to cancel each other. The changing phase relationship of two such signals causes intermittent fading.

Shore Line Effect. When ground waves pass over a coast line at an oblique angle, they tend to be refracted because of the difference in conductivity between the land and the water. The resultant change in direction is known as shore line effect. This factor causes some inaccuracy of radio bearings whenever a coast line lies between the receiver and the transmitter.

Another factor which produces erroneous bearing indications is bending and splitting of ground waves in mountainous areas, or over areas of natural magnetic disturbance.

Interference. Unwanted signals in a receiver are called interference. The intentional production of such interference to obstruct communication is called *jamming.* More detailed information on interference and jamming is presented in Chapter 25.

Weather Disturbances. Electrical discharges produced by thunderstorms generate signals in the low and medium frequency bands which can masquerade as a desired signal. Because of this, a radio compass is usually erratic in thunderstorm areas and may even point to an area of electrical disturbance rather than to the desired station. In thunderstorm areas, LF and MF communications may become garbled or covered by static.

Antennas

Antennas may be classified as either nondirectional or directional.

NONDIRECTIONAL ANTENNAS. A nondirectional antenna is one which radiates or receives radio energy equally well in all directions. The most common nondirectional antenna is a vertical metal mast mounted on an insulated base. This antenna has almost no top surface and radiates comparatively little energy directly above the mast.

Vertical nondirectional antennas are commonly used in the LF and MF bands for marine and aeronautical navigation beacons and for commercial broadcast stations. Figure 9-5 shows the transmission pattern of a vertical antenna.

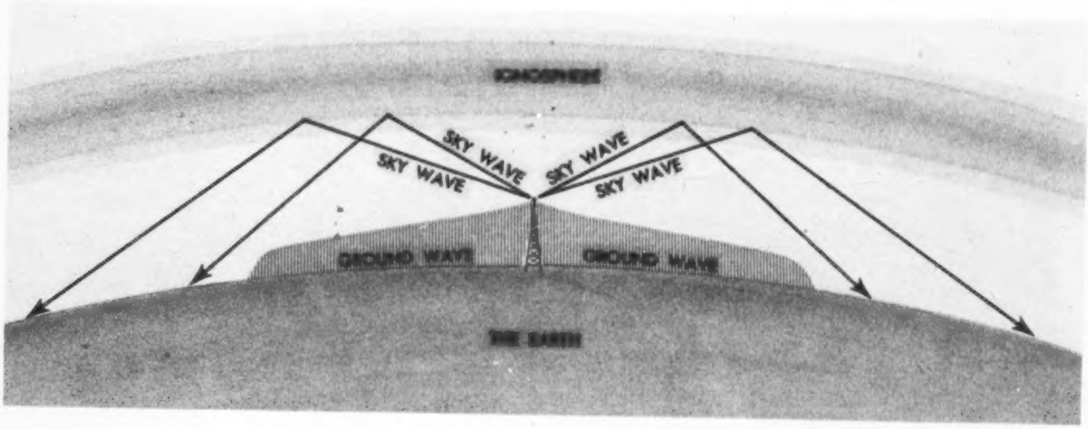


Figure 9-5. Transmission Pattern of a Vertical Antenna

DIRECTIONAL ANTENNAS. A directional antenna is one which either transmits or receives energy more efficiently in one or more directions than others. Thus, directional information can be obtained by orienting a directional antenna for either maximum or minimum signal strength from a received signal.

There are many methods of achieving directional transmission and reception, but the *loop antenna* is perhaps the simplest and the most widely used in airborne navigational equipment. The loop antenna can be used for either directional transmission or directional reception.

When the plane of the loop antenna is parallel to the path of a transmitted signal, maximum voltage is induced in its coils, causing the signal to be received at maximum strength (see figure 9-6). When the plane of the antenna is perpendicular to the path of a transmitted signal, minimum voltage is induced in its coil, and the signal is received at minimum strength. These characteristics give the loop antenna its ability to "sense" the direction of the path traveled by the signals it receives.

The convenient properties of a combined signal from a loop and wire antenna system make possible the automatic direction finder (ADF) which continuously presents the bearing of the radio transmitting station to which it is tuned.

RADIO AIDS TO NAVIGATION

Radio Beacons

Radio beacons transmit a nondirectional signal which is easily identified as a specific station. If an aircraft has ADF equipment, the direction of the beacon from the aircraft can be determined. Several names are given to radio beacons, depending on their specialized functions. A *compass locator* is a radio beacon, usually of low power, associated with an instrument landing system (ILS). A *homer* is a radio beacon associated with an airport. Most radio beacons transmit on frequencies between 200 and 400 KHz.

Fixing with the radio compass is relatively easy, but depends on the availability and proximity of stations. ADF bearings are used as LOPs and are treated as explained in Chapter 6. To obtain a bearing, the navigator rotates the compass card on the bearing indicator (figure 9-7) until any desired reference is under the index. Set 360° under the index for relative bearings; set true heading for true bearings, and set magnetic heading for magnetic bearings.

Marker Beacons

Most marker beacons operate on a frequency of 75 KHz and are designed to give local position

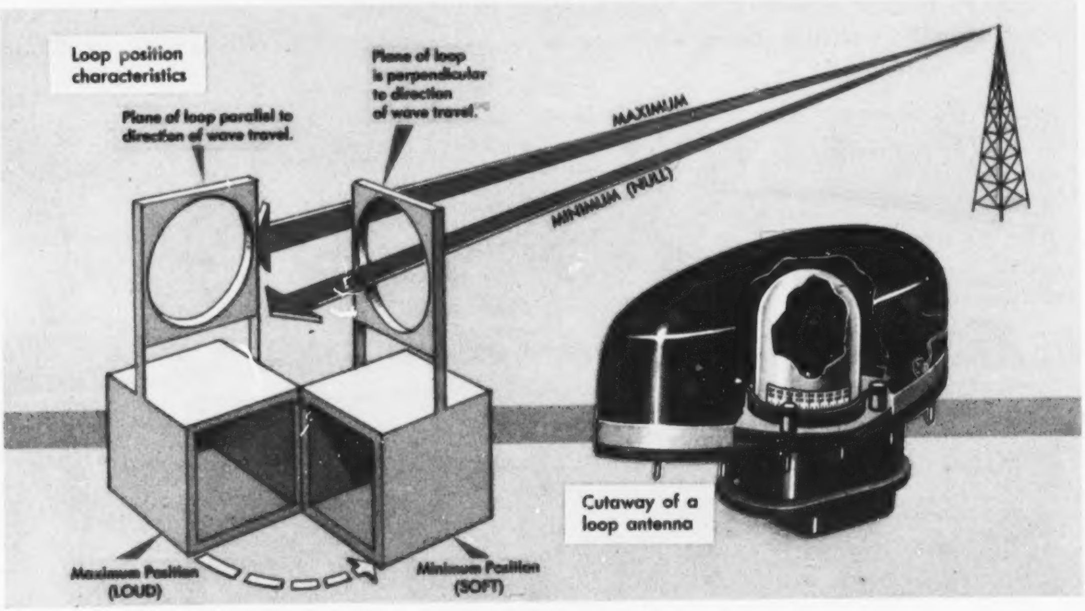

Loop position characteristics
Plane of loop parallel to direction of wave travel.
Plane of loop is perpendicular to direction of wave travel.
MAXIMUM
MINIMUM (NULL)
Cutaway of a loop antenna
Maximum Position (LOUD)
Minimum Position (SOFT)

Figure 9-6. Loop Antenna

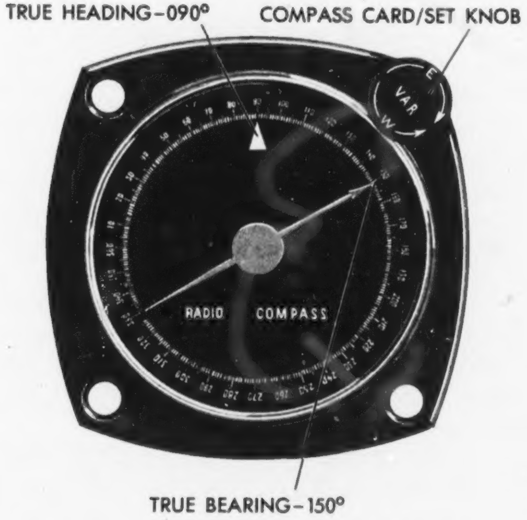

TRUE HEADING-090°
COMPASS CARD/SET KNOB
E
VAR
W
RADIO
COMPASS
TRUE BEARING-150°

Figure 9-7. Radio Compass Bearing Indicator

information, usually by narrow vertical beams. A *fan marker* transmits a vertical beam whose cross section is either lens shaped or bone shaped. *Z markers* provide vertical beams with a circular cross section. The coded flashes of a light on the pilot's instrument panel and an aural signal are the only indications of passing over a marker beacon.

Radio Ranges

LOW FREQUENCY. Low frequency radio ranges are directional transmitting stations which operate between 200 and 400 KHz. Although other aids have made them obsolete, some range stations still exist in the U.S. and they are more common in other countries. The directional transmission of a radio range station is limited to four beams or legs which are approximately 3° in width. If an aircraft is not positioned exactly on one of the four beams, it is possible to identify only the quadrant between beams in which the aircraft is located. The four quadrants are alternately identified as "A" or "N" with the quadrant containing true north always being an "N" quadrant. The "A" and "N" signals are transmitted in International Morse Code with precise spacing such that a solid tone is heard when the aircraft is positioned on one of the station's four beams. This tone is called the "on course" signal. (See figure 9-8.)

It must be noted that after identifying the course signal or the "A" or "N" signal, good dead reckoning information is necessary to identify the correct course or quadrant. The direction to the station can also be determined through the use of ADF equipment.

Directly over the range is a characteristic cone of silence; an area in which no signal is heard.

A "Z" marker is usually located at a low-frequency radio range station, and its vertical beam, centered in the cone of silence, is used to identify station passage.

OMNIRANGE. The VHF omni-directional range

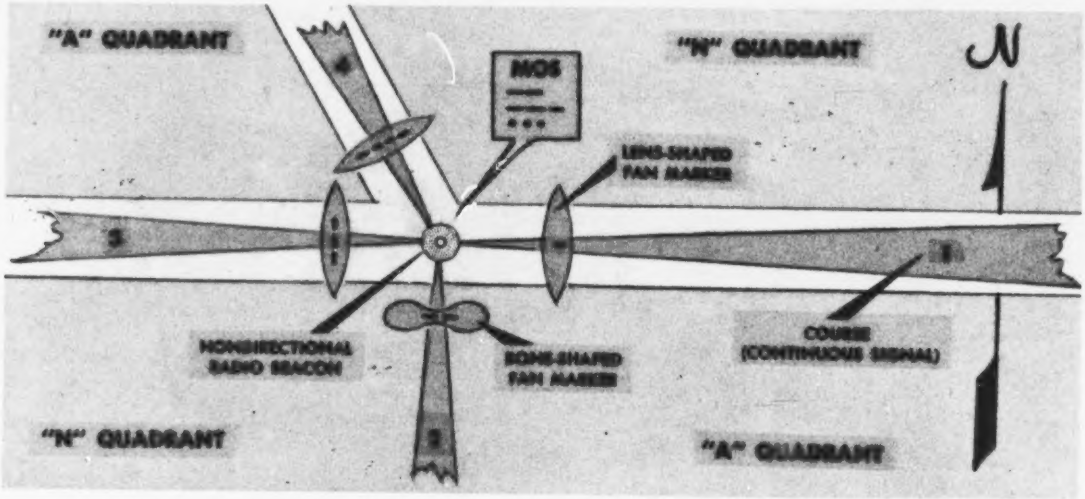

"A" QUADRANT
4
MOS
"N" QUADRANT
N
LENS-SHAPED FAN MARKER
3
1
NONDIRECTIONAL RADIO BEACON
BONE-SHAPED FAN MARKER
COURSE (CONTINUOUS SIGNAL)
"N" QUADRANT
2
"A" QUADRANT

Figure 9-8. Radio Range Symbols

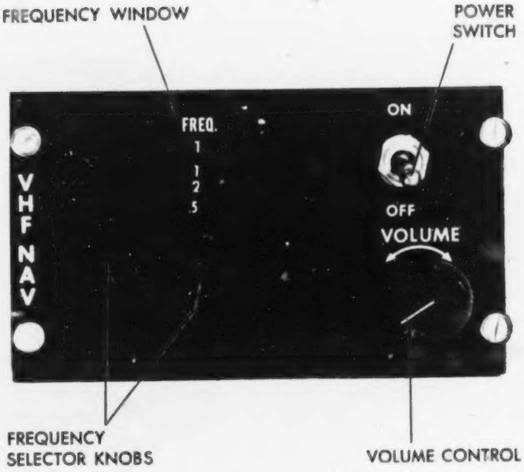

FREQUENCY WINDOW
POWER SWITCH
FREQ.
1
1
2
5
ON
OFF
VOLUME
V H F
N A V
FREQUENCY SELECTOR KNOBS
VOLUME CONTROL

Figure 9-9. VOR Control Panel

(VOR) is a radio facility which has eliminated many of the difficulties associated with low-frequency radio navigation. VOR stations operate between 108.0 and 117.0 MHz. Station identifiers are given in code or voice, or by both code and voice transmission. Unlike the low-frequency radio range, a VOR station provides an infinite number of radials or courses.

For simplicity, however, only 360 radials are considered possible. These radials are identified by their magnetic bearing *from* the station. Regardless of heading, an aircraft on the 090° radial is physically located east of the station. Flying to the station on this radial, the magnetic course (MC) is 270°.

Since VOR transmissions are in the VHF band, signals are not affected by atmospheric disturbances or other factors common to lower frequencies. They are, however, subject to line-of-sight reception, and reception distance varies directly with the altitude of the aircraft.

Control Panel. A VOR control panel contains a power switch, frequency selector knobs, a frequency window, and a volume control (figure 9-9). To tune a VOR receiver, turn the power switch ON, select the desired frequency, and identify the station.

Indicators. VOR equipment has two indicators. These are the course indicator and the radio magnetic indicator (RMI). They are shown in figures 9-10 and 9-11 respectively.

The course indicator has eight significant features:

- TO-FROM indicator
- Glide slope and course warning flags.
- Course selector window
- Marker beacon light
- Glide slope indicator
- Heading pointer
- Course deviation indicator (CDI)
- Course set knob

The TO-FROM indicator shows whether the radial set in the course selector window is to or from the station, and the CDI represents this radial. If the aircraft is to the right of the radial, the CDI is to the left of center on the course indicator. The glide slope indicator is similar to

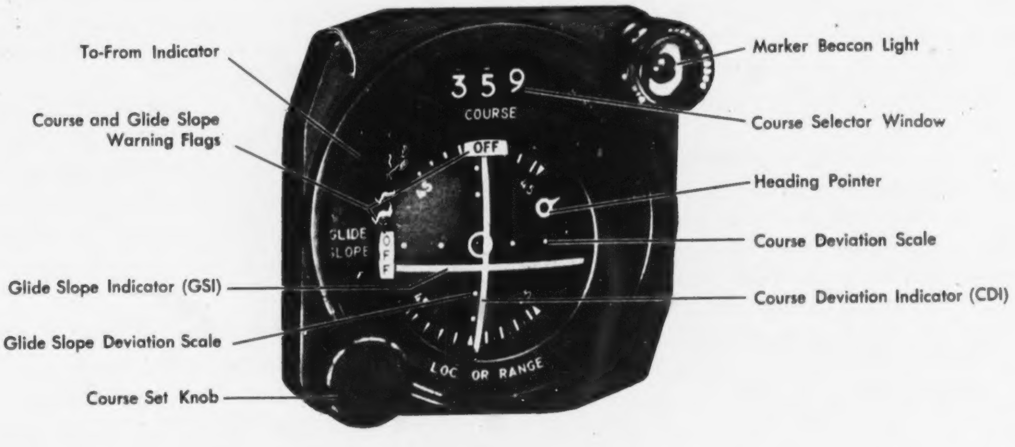

To-From Indicator
Course and Glide Slope Warning Flags
Glide Slope Indicator (GSI)
Glide Slope Deviation Scale
Course Set Knob
Marker Beacon Light
Course Selector Window
Heading Pointer
Course Deviation Scale
Course Deviation Indicator (CDI)
3 5 9
COURSE
OFF
GLIDE SLOPE
OFF
LOC OR RANGE

Figure 9-10. Course Indicator

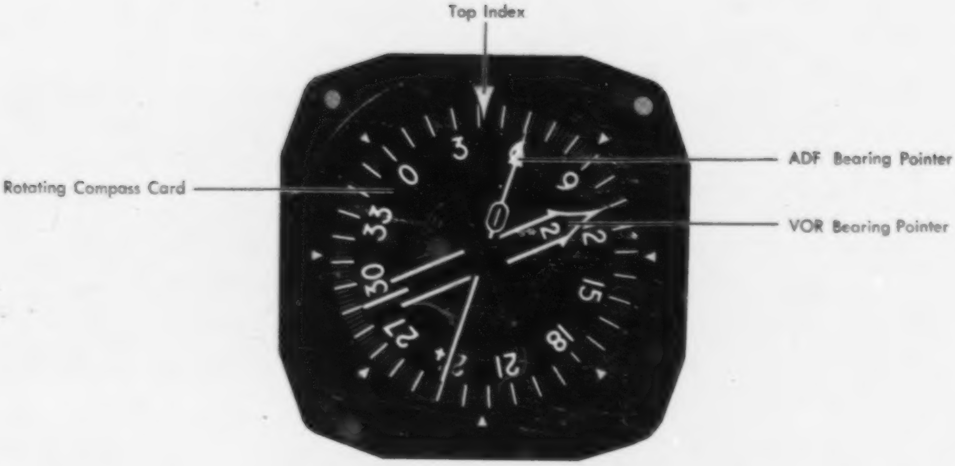


Figure 9-11. Radio Magnetic Indicator (RMI)

the CDI but represents the glide slope transmitted by an instrument landing system. If the glide slope indicator is below the center of the course indicator, the aircraft is above the glide slope. The glide slope and course warning flags inform the user that either the glide slope indicator or the CDI is inoperative, or that the signals received are too weak to be used. The heading pointer indicates the difference, to the right or left, between the aircraft magnetic heading and the radial set in the course selection window. The marker beacon light flashes when passing over a marker beacon.

The RMI is a bearing indicator, usually with two pointers and a movable compass rose. The compass rose rotates as the aircraft turns indicating the compass heading of the aircraft under the top index at all times. Therefore, all bearings taken from the RMI pointers are magnetic bearings.

Fixing with the VOR is similar to fixing with the low frequency radio; however, since all VOR bearings are magnetic, variation must be applied to obtain true bearing. One rule to remember is to use the variation at the VOR station for VOR LOPs and variation at the aircraft for ADF LOPs. LOPs may be taken from the pointers on the RMI or by centering the CDI and reading the radial in the course selection window.

TACAN

Tactical Air Navigation (TACAN) is a short-range navigation system which supplies continuous, accurate, slant-range distances and bearings. The station identifier is transmitted at 35-second intervals in International Morse Code.

As with VOR, the major disadvantages of low-frequency ranges (static interference and a limited number of navigational courses) are eliminated with TACAN. Much like VOR, TACAN provides an infinite number of courses to or from the TACAN station, and the same instruments (course indicator and RMI) are used to obtain bearing information.

TACAN operates in the UHF band and has a total of 126 channels. Airborne Distance Measuring Equipment (DME) transmits on channels in the 1025-1150 MHz range; associated ground-to-air transmissions are made between 962-1024 MHz or 1151-1213 MHz.

Position information is obtained by using a multi-channel airborne transmitter-receiver (transceiver). Radio signals transmitted over a selected channel convey both distance and bearing information. The equipment is designed to present range information out to 195 nautical miles at high altitudes.

Accuracy of the DME is on the order of plus or minus 600 feet, plus two tenths percent of the distance being measured. Thus, at a distance of 10 nautical miles from the facility, the maximum distance error is plus or minus 720 feet. Distance is measured slant-range. For practical purposes, this may be regarded as horizontal distance except when the aircraft is very close to the station.

The ground equipment consists of a receiver-transmitter combination (transponder) and a rotating antenna for transmission of distance and bearing information. Transmission of erroneous signals is possible during calibration of the station; therefore, when calibration or ground maintenance is done, the station identifier is turned off. Always monitor *and identify* the station before using any bearing or range information.

If an aircraft is in a position to receive two stations on the same frequency, the strongest signal will predominate. In an area of approximately equal signal strength from two stations on the same frequency, TACAN equipment may seek first one station and then the other.

TUNING. TACAN control box is shown in figure 9-12. Turning the OFF, REC, T/R switch to the T/R or REC position turns the equipment on. (If the switch is moved to the REC position, the DME will not operate and only bearing information will be displayed.) After the equipment is turned on, select the desired channel between 1 and 126 by using the outer knob to select the first two digits in the channel number (0 to 12) and the inner knob to select the third digit (0-9). For example, to select channel 115, select the first two digits (11) with the outer knob and the third digit (5) with the inner knob. Adjust the volume and identify the station.

DISTANCE MEASURING EQUIPMENT (DME). Distance is determined with TACAN equipment by measuring the elapsed time between transmission of interrogating pulses from the airborne set and reception of corresponding reply pulses from the ground station. The aircraft transceiver starts the process by sending out the distance interrogation pulse signals. Receipt of these signals by the ground station receiver triggers its transmitter and it sends out the distance reply pulse signals. These pulses require about 12 microseconds round-trip travel time per NM of distance from the ground station. The range indicator (figure 9-13) displays distance to the TACAN station in NM.

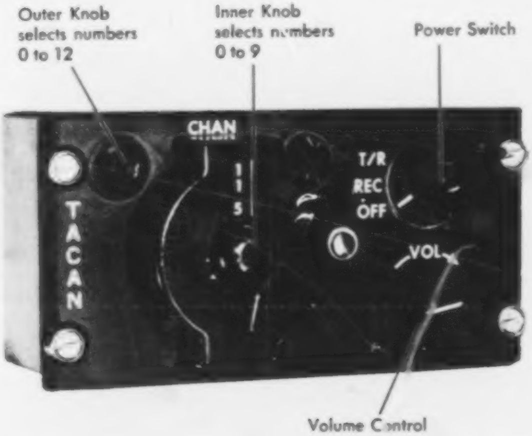

Outer Knob selects numbers 0 to 12
Inner Knob selects numbers 0 to 9
Power Switch
CHAN
1
1
5
T/R
REC
OFF
VOL
TACAN
Volume Control

Figure 9-12. TACAN Control Box

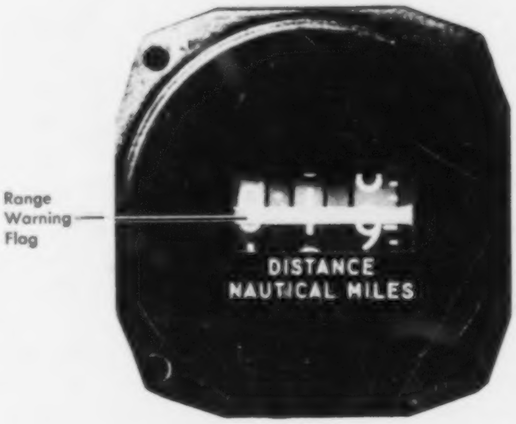


Figure 9-13. Range Indicator

Since a large number of aircraft could be interrogating the same station, the airborne set must sort out only the pulses which are replies to its own interrogations. Interrogation pulses are transmitted on an irregular, random basis by the airborne set which then "searches" for replies synchronized to its own interrogations. If the signals are interrupted, a memory circuit maintains the last distance indication on the range indicator for approximately 10 seconds to prevent the search operation from recurring. The searching process starts automatically whenever the airborne set is tuned to a new station or when there is a major interruption in signals. Depending upon the actual distance of the aircraft from the station, the searching process may require up to 22 seconds.

POSITIONING BY TACAN. Bearing information is obtained in the same manner and on the same instruments as VOR bearings. Magnetic variation at the station is used to convert magnetic bearing to a true bearing. The position of the aircraft is determined by obtaining the bearing and the reading from the range indicator simultaneously and then plotting the true bearing and range from the station towards the aircraft.

VORTAC

VORTAC is a system consisting of a VOR station and a TACAN station operating simultaneously with the antennas of both located at a common geographical point. Aircraft equipped with VOR and distance measuring equipment are able to receive bearings from the VOR station and distances from the TACAN station. Aircraft equipped with TACAN receive bearings and distances from the TACAN portion of the station.

CONSOL/CONSOLAN. During World War II, Germany developed a navigation system called *Sonne*. Following the war the British further developed the system under the name *Consol* and several stations operating in the LF band have been installed in western Europe. The U.S. system called *Consolan*, also has several stations operating in the same band.

Consol and Consolan differ from other hyperbolic systems in that three antennas are located in a straight line (antenna base line) and are closely spaced. This aid is often considered directional rather than hyperbolic because great-circle bearings are plotted from the position of the center antenna.

The usable range of Consol and Consolan is approximately 1,000 miles during the day and 1,200 to 1,400 miles at night. Bearings are most accurate along a line perpendicular to the antenna base line and accuracy decreases toward the base line extensions. The total usable area is approximately 240° for Consol and 280° for Consolan. The usable circumference is divided into two sections, one on each side of the base line and centered on a perpendicular bisector to the base line (see figure 9-14). Two unreliable areas, of approximately 40° each for Consolan and 60° each for Consol, are centered on the base line extensions. Unreliable sections are labeled on Consol charts. A typical Consol chart is shown in figure 9-15.

In the daytime, at 1000 miles from the station, LOP errors of from 6 miles at the bisector centerline to 24 miles at the outer edges of the usable areas (approaching the base line) are not uncommon. At night these LOP errors may increase to as much as 10 and 40 miles from the station. Interaction between sky waves and ground waves or high atmospheric noise can cause even larger errors.

CONSOL/CONSOLAN SIGNALS. Consol and Consolan signals are transmitted as a series of dots and dashes. The phase of signals transmitted from the two end antennas is rotated with respect to the signal of the center antenna such that the radiation pattern consists of many lobes rotating around the middle antenna. Rotation is clockwise on one side of the base line and counterclockwise on the other side. Alternate lobes, or sectors, contain dot and dash signals which merge into a tone or *equisignal* at the sector boundaries.

The duration of a transmission sequence may be as short as 30 seconds or as long as a minute depending on the particular station being used. During each sequence, a total of 60 dots and dashes is transmitted. The transmission sequence, heard by the operator, is shown in figure 9-16.

To obtain LOPs from a Consol or Consolan station, only an LF receiver equipped with a beat frequency oscillator (BFL) is needed. Tune the receiver to the desired station frequency and turn on the BFO (CW-Switch). If the receiver being used is equipped with both sensing and loop antennas, select the sensing antenna (ANT).

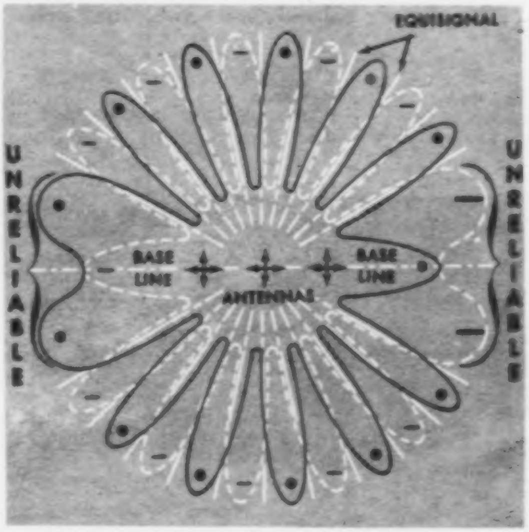


Figure 9-14. Consolan Station

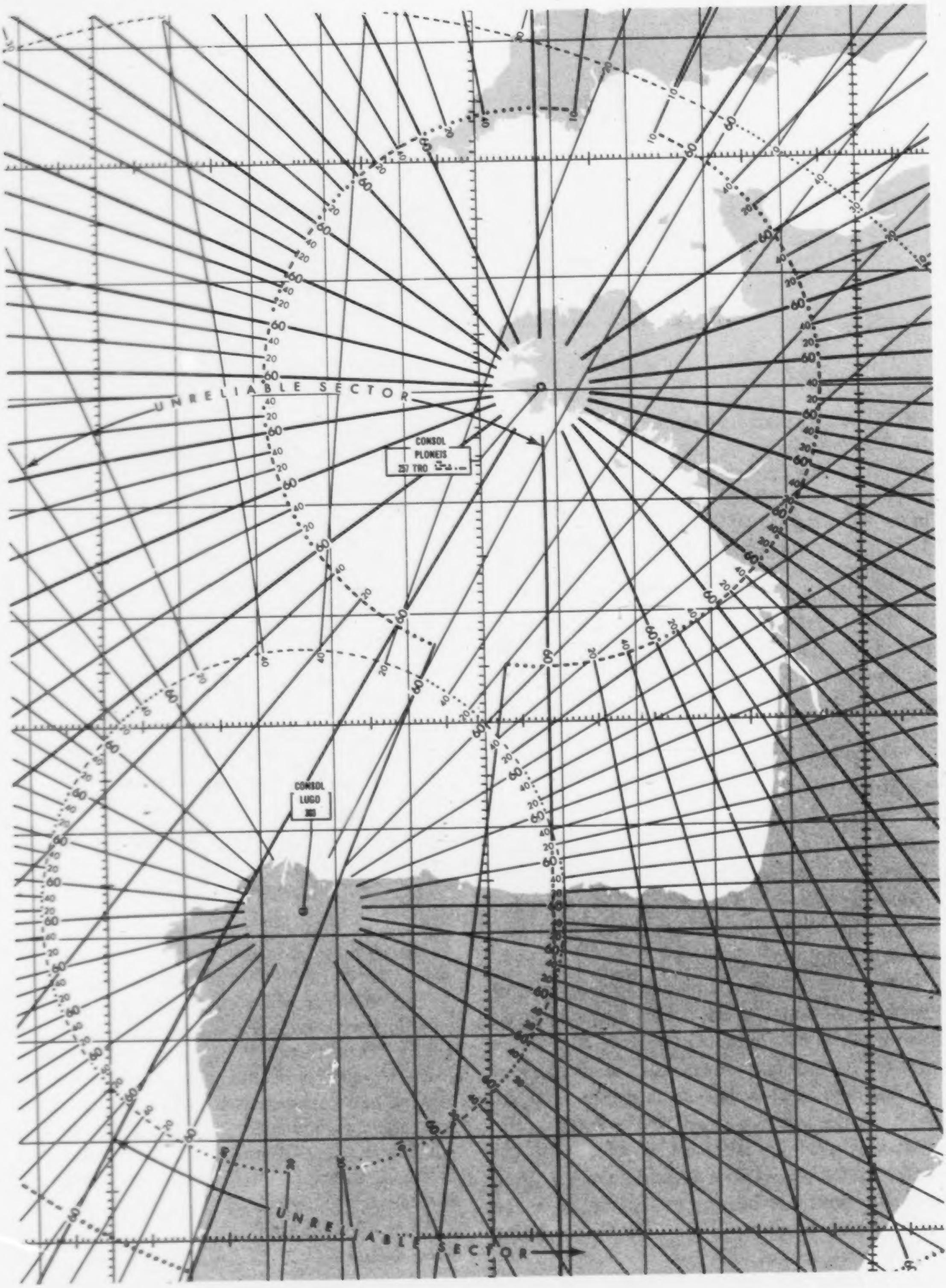
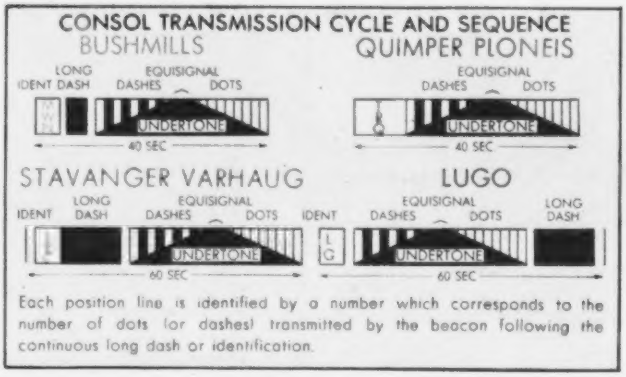

UNRELIABLE SECTOR
CONSOL
PLONEIS
257 TRO
CONSOL
LUGO
UNRELIABLE SECTOR

Figure 9-15. Consol Chart



Each position line is identified by a number which corresponds to the number of dots (or dashes) transmitted by the beacon following the continuous long dash or identification.

Figure 9-16. Consol Transmission and Sequence

NOTE: If excessive interference is present, selecting the loop antenna, after initial tuning, will sometimes improve reception.

The procedure for obtaining an LOP is shown in the following example:

1. Tune the LF receiver to the desired station frequency.
2. Identify the station.
3. Count the number of dots or dashes transmitted before the equisignal (for example, 15 dots are heard).
4. Note the time of the equisignal (this is the time of LOP).
5. Count the number of dots or dashes after the equisignal (dashes—39).
6. Total the number of characters received before and after the equisignal (dots and dashes—54). This total is subtracted from 60 and the remainder (6) is applied equally between the dots and dashes to obtain the corrected dot and dash count (18 dots and 42 dashes).
7. Plot an LOP representing the sum of dots or dashes (18 dots) heard before the equisignal. To plot the LOP, locate the number of dots (or dashes) on the chart which corresponds to those counted and draw a line as is shown in figure 9-17. A DR position or an ADF bearing to the station is used to determine in which dot (or dash) sector the LOP is located. Only a gross error in either the bearing to the station or the DR position could cause the LOP to be plotted in the wrong sector.

NOTE: AVC (automatic volume control) cannot be used in the reception of Consol signals. This is because the dot-dash signals from the Consolan transmitter are signals of relative intensity. Since AVC causes all signals to be of the same intensity, the variations in the signal could not be detected.

CAUTION

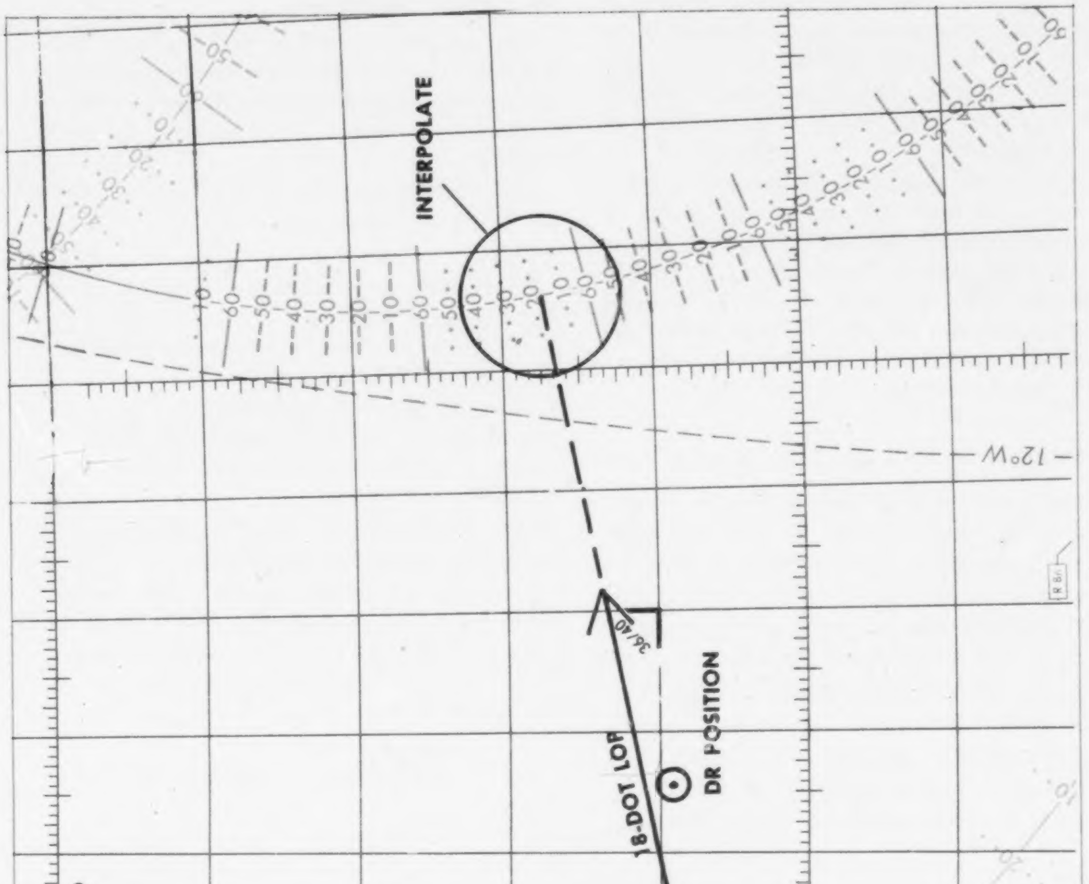
1. At night, always take a series of readings, particularly when 300 to 700 miles from the station. Wide variation in successive counts is an indication of ground wave/sky wave interference. These bearings should be used with caution or disregarded altogether.
2. Consol LOPs should never be used within 25 miles of the station and Consolan LOPs should not be used within 50 miles of the station.

COMMUNICATION

Air/ground communications can be achieved through the use of many types of equipment. Although older LF radios are still sometimes used, greater reliability has come with equipment which uses higher frequency ranges (HF, VHF, and UHF). These frequency bands are relatively static free and are less susceptible to outside interference. It must be remembered, however, that the higher the frequency the more nearly the transmission will follow a line-of-sight path. As frequency increases, therefore, communication range is decreased.

Long Range

Systems used for long range radio communication between aircraft and ground stations may be



INTERPOLATE
INTERPOLATE
18-DOT LOP
DR POSITION
36/40
40°
20°
12°W
DE SÃO MIGUEL
350
40/40

Figure 9-17. Plotting a Consol LOP

either amplitude modulation (AM) or single sideband (SSB) transmission. Single sideband transmitters concentrate all available power into one sideband; therefore, SSB is much more efficient and has greater range than an AM transmitter of the same power.

Although HF ground waves attenuate rapidly, sky waves at these frequencies are capable of transmitting communication at distances up to 12,000 miles or more, depending on ionospheric conditions. HF equipment on aircraft is used mostly in remote areas where VHF or UHF communication is not possible because of the distances which must be spanned.

Short Range Air-to-Air and Air-to-Ground

Short range air-to-air and air-to-ground communications are confined to the VHF and UHF bands. Transmission and reception frequencies are crystal controlled on all newer pieces of equipment. VHF channels are spaced at 50 KHz intervals from 116 to 149.95 MHz and UHF channels are spaced 50 KHz apart from 225.0 to 399.9 MHz. Most UHF transceivers have a manual frequency selection capability in addition to a number of preset channels. Transmission and reception is accomplished with a single antenna.

IFF/SIF

Identification Friend or Foe (IFF) was first used during World War II and is a small airborne transponder which transmits coded signals when triggered (interrogated) by a ground-based search radar. Pulses received from the airborne equipment produce "blips" on the ground-based radar scope and are used to positively identify and locate aircraft.

The addition of a Selective Identification Feature (SIF) allows faster isolation and identification of any aircraft under surveillance. Positive identification can be established and maintained by the ground controller when a designated SIF "mode" and "code" is set into the airborne transponder. Initial identification is usually established by using the "IP" or "flash" function of the airborne set. Tracking is maintained by setting the requested mode and code into the airborne equipment.

AN/APX-64 Transponder

The AN/APX-64 (figure 9-18) provides normal IFF Mach X (SIF) operation in the familiar modes. Two additional modes available are mode C for altitude reporting and mode 4, which is classified.

IFF MASTER CONTROL KNOB. This is a five-position rotary switch.

- OFF.
- STDY—No transmission capability until warm-up delay has cycled.
- LOW—Receiver sensitivity is reduced and only local interrogations are answered.
- NORM—Full-range operation.
- EMER—An emergency-indicating pulse is transmitted each time a mode 1, 2, or 3/A interrogation is recognized.

IFF MODE SWITCHES. Four three-position toggle switches are used to select the desired operating modes. Mode 1 is the security identity mode. Mode 2 is for personal identity. Mode 3/A is for traffic identity. Mode C is the altitude reporting mode. The three positions are identical for all four toggle switches.

- OUT—Mode disabled.
- ON—Allows normal response to mode interrogation.
- TEST—Spring-loaded for in-flight test and lights test lamp when the reply is satisfactory.

CODE SELECTOR KNOBS. Used to set desired codes.

IDENTIFICATION OF POSITION SWITCH. A three-position toggle switch that enables IDENT replies.

- IDENT—Spring-loaded and initiates reply for 30 seconds.
- OFF.
- MIC—Initiates a reply for 30 seconds whenever the MIC button is depressed and the interphone transmitter selector knob is set to UHF.

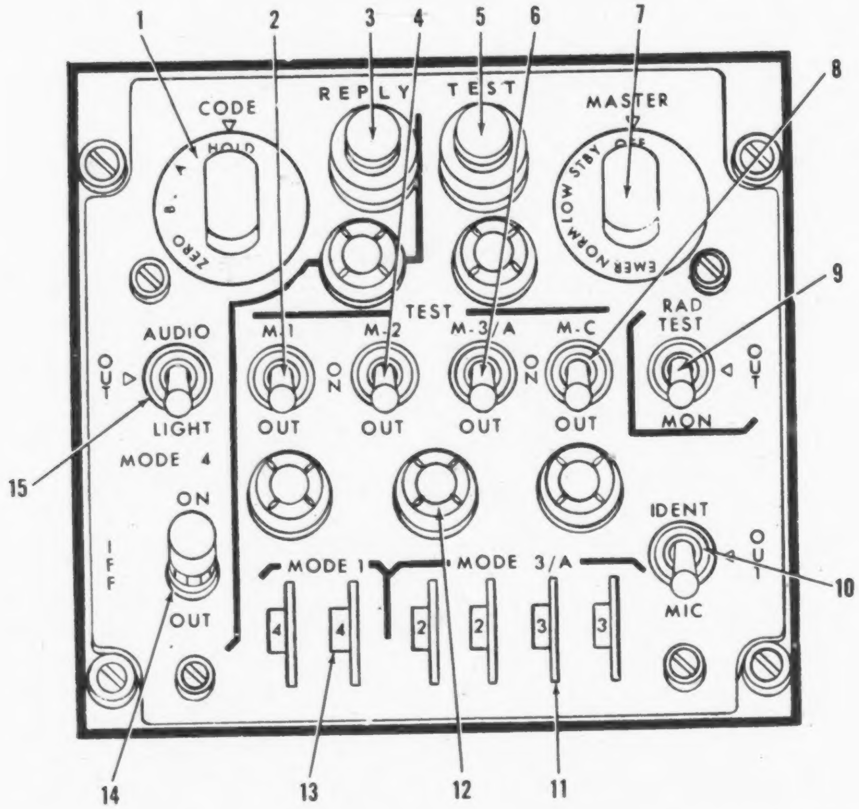
RADAR TEST/MONITOR SWITCH. Used by ground maintenance and in conjunction with the test lamp to monitor all responses in any SIF mode.

TEST LAMP. Lights in conjunction with proper mode/test conditions and RAD TEST/MON SW interrogations.

MODE 4. The Mode 4 enable switch controls the operation of Mode 4. The Mode 4 control switch has three positions which permits aural and reply lamp monitoring of valid mode 4 interrogations and replies in AUDIO.

- OUT—No monitoring capability.
- LIGHT—Reply lamp monitoring only.
- REPLY LAMP—Used with Mode 4 only.

MODE 4 code control knob. Classified.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
CODE
HOLD
A
B
ZERO
REPLY
TEST
MASTER
OFF
STBY
LOW
NORM
EMER
TEST
M-1
M-2
M-3/A
M-C
ON
ON
OUT
OUT
OUT
OUT
AUDIO
OUT
LIGHT
MODE 4
RAD TEST
OUT
MON
IFF
ON
OUT
IDENT
OUT
MIC
MODE 1
MODE 3/A
4
4
2
2
3
3

1. MODE 4 CODE SELECTOR KNOB
2. MODE 1 ENABLE/ TEST SWITCH
3. REPLY INDICATOR LIGHT
4. MODE 2 ENABLE/ TEST SWITCH
5. TEST INDICATOR LIGHT
6. MODE 3/A ENABLE/ TEST SWITCH
7. IFF/SIF MASTER CONTROL KNOB
8. MODE C ENABLE/ TEST SWITCH
9. RADAR TEST/ MONITOR ENABLE SWITCH
10. IDENTIFICATION OF POSITION ENABLE SWITCH
11. MODE 3/A CODE SELECT WHEELS
12. PANEL LAMP
13. MODE 1 CODE SELECT WHEELS
14. MODE 4 ENABLE SWITCH
15. MODE 4 REPLY INDICATION SELECT SWITCH

Figure 9-18. IFF/SIF Control Panel

CHAPTER 10

Radar

BASIC PRINCIPLES

The manner in which a bat successfully avoids the walls and jutting stalactites of a totally dark cave makes fascinating reading. Investigation has shown that if its mouth is gagged or its hearing impaired the bat can no longer avoid such obstacles. From this, it has been concluded that the bat's uncanny ability to navigate derives from the emission of cries—inaudible to the human ear—which are then reflected from any obstacles in its path. These reflected echoes allow the bat to orient himself with respect to the obstacles and thus maneuver to avoid them.

The fundamental principle of radar is closely akin to that used by the bat. The basis of the system has been known theoretically since the time of Hertz, who in 1888 successfully demonstrated the transfer of electromagnetic energy in space and showed that such energy is capable of reflection. The *transmission* of electromagnetic energy between two points was developed as "radio," but it was not until 1922 that practical use of the *reflection* properties of such energy was conceived. The idea of measuring the elapsed time between the transmission of a radio signal and receipt of its reflected *echo* from a surface originated nearly simultaneously in the United States and England. In the United States, two scientists working with air-to-ground signals noticed that ships moving in the nearby Potomac River distorted the pattern of these signals. In 1925, the same scientists were able to measure the time required for a short burst, or pulse, of radio energy to travel to the ionosphere and return. Following this success, it was realized that the radar principle could be applied to the detection of other objects, including ships and aircraft.

By the beginning of World War II, the Army and Navy had developed equipment appropriate to their respective fields. During and following the war, the rapid advance in theory and technological skill brought improvements and additional applications of the early equipment. By suitable instrumentation it is now possible to measure accurately the distance and direction of a reflecting surface in space—whether it is an aircraft, a ship, a hurricane, or a prominent feature of the terrain—even under conditions of darkness or restricted visibility. For these reasons, radar has become a valuable navigational tool.

There are many different types of radar sets currently in use in the Air Force. For the navigator, they can be divided into two classes: (1) those designed for navigation, search, and weather identification, to which no computer has been attached, and (2) those designed principally for use with high accuracy bombing-navigation computers. With the former, fixing can be accomplished only by using ranges or bearings, or both. With the latter, the position of the aircraft in latitude and longitude is continuously displayed on the navigation computer which is periodically corrected by the radar.

In view of the great variety of radar sets in use, it would be impractical to cover in this manual the specific operating procedures for each. Therefore, the following material is limited to the *general* procedures for using radar as an aid to navigation. For detailed information concerning a specific set, consult the appropriate manual or technical order.

As noted previously, the fundamental principle of radar may be likened to that of relating sound to its echo. Thus, a ship sometimes determines its distance from a cliff at the water's edge by blowing its whistle and timing the interval until the echo is received. Since sound travels at a known speed (approximately 1,100 feet per second in air), the total distance traveled equals the speed times the time interval, and one-half this distance (because the sound must travel to the cliff and *back* before the echo is heard) is the distance to the cliff. Thus, if the time interval is 8 seconds, the distance to the cliff is

$$\frac{1{,}100 \times 8}{2} = 4{,}400 \text{ ft} = 0.725 \text{ NM}$$

The same principle applies to radar, which uses the reflected echo of electromagnetic radiation traveling at the speed of light. This speed is approximately 162,000 nautical miles per second; it may also be expressed as 985 feet per microsecond. If the interval between the transmission of the signal and return of the echo is 200 microseconds, the distance to the target is

$$\frac{985 \times 200}{2} = 98{,}500 \text{ ft} = 16.2 \text{ NM}$$

TYPICAL RADAR SET

Components

In addition to the power supply, a radar set contains five major units: the timer, the transmitter, the antenna, the receiver, and the indicator as shown in figure 10-1. Their functions are briefly described as follows:

The *timer*, or modulator, is the heart of the radar system. Its function is to insure that all circuits connected with the system operate in a definite time relationship with each other and that the time interval between transmitted pulses is of the proper duration. The timer "triggers" the other units into operation.

The *transmitter* is similar to the radio transmitters described in the chapter on radio except that it operates in the super high frequency band and operates for very short periods of time.

The *antenna* is a "parabolic dish" which directs the transmitted energy into a narrow wedge or into a conical beam like that of a searchlight. It serves not only for transmission but for reception as well.

The *receiver*, like the transmitter, is similar to a radio receiver. Its main function is to amplify the relatively weak echoes which return to the antenna.

The *indicator* for the radar set is a special vacuum tube called a *cathode ray tube* (*CRT*). It is similar to the picture tube of a television receiver. The CRT is commonly called the *scope* (from oscilloscope). An electromagnetic CRT, the type used in most radar sets, is illustrated in figure 10-2. It is composed of an electron gun, a focusing magnet, and a set of deflection coils. The function of the electron gun is to produce a thin electron stream, or beam. This beam is so acted upon by the focusing magnet that the focal point of the beam in a properly adjusted CRT is at the face of the tube. The CRT face is coated with a fluorescent compound which glows when struck by the electron beam. The picture seen is thus a small bright spot.

The location of an object by means of these five units of a radar set involves the simultaneous

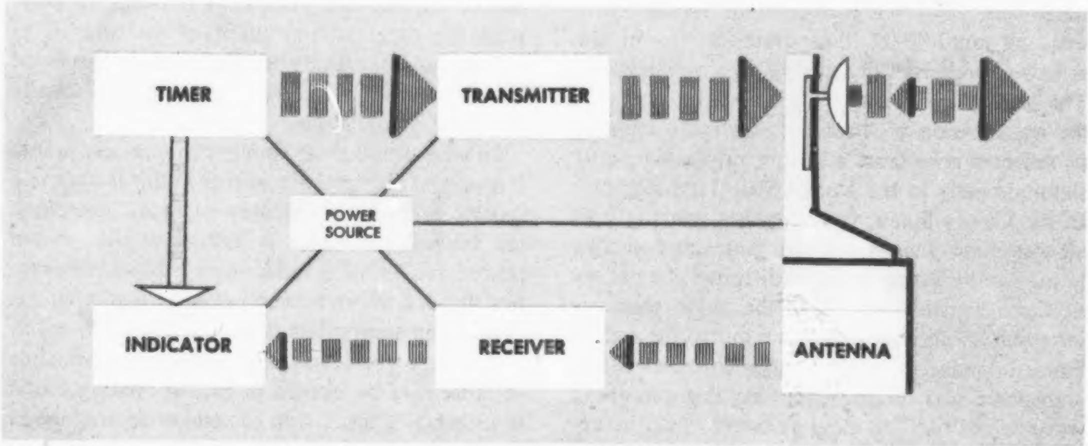


Figure 10-1. Components of a Typical Radar System

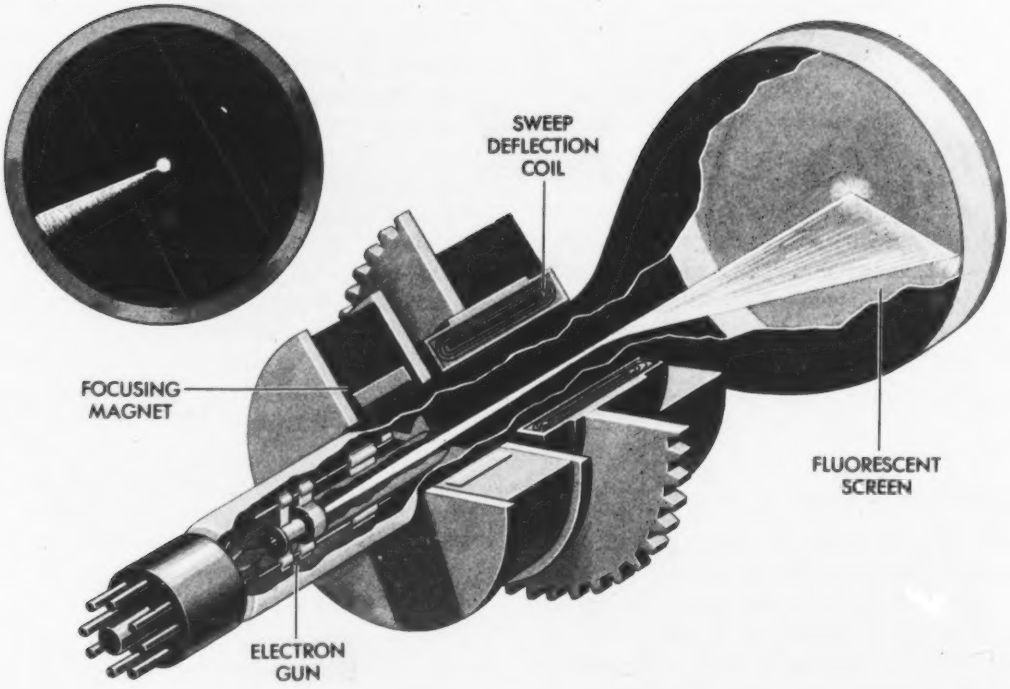


Figure 10-2. Electromagnetic Cathode Ray Tube (CRT)

solution of two separate problems. First, the time interval between the transmitted pulse and its echo must be accurately measured and presented as *range* on the indicator. Second, the direction in which each signal is transmitted must be indicated, giving the *bearing* of the object.

Measurement of Range

The radar cycle may best be explained by discussing first the life of a single pulse as it is affected by each of the components shown in figure 10-1. The cycle begins when the timer triggers the transmitter. A powerful pulse of radio energy is generated there which is then emitted from the antenna. As soon as the pulse leaves the antenna, the antenna is automatically disconnected from the transmitter and connected to the receiver. If an echo returns, it is amplified by the receiver and sent to the indicator for display.

At the same time that the timer triggers the transmitter, it also sends a trigger signal to the indicator. Here, a circuit is actuated which causes the current in the deflection coils to rise at a linear (uniform) rate. The rising current, in turn, causes the spot to be deflected radially outward from the center of the scope. The spot thus traces a faint line on the scope; this line is called the *sweep*. If no echo is received, the intensity of the sweep remains uniform throughout its entire length. However, if an echo is returned, it is so applied to the CRT that it intensifies the spot and brightens momentarily a short segment of the sweep. Since the sweep is linear and begins with the emission of the transmitted pulse, the point at which the echo brightens the sweep will be an indication of the range to the object causing the echo.

The progressive positions of the pulse in space also indicate the corresponding positions of the electron beam as it sweeps across the face of the CRT. If the radius of the scope represents 40 miles and the "return" appears at three-quarters of the distance from the scope center to its periphery, the target is represented as being about 30 miles away.

Of interest here is the extremely short time scale which is used. In the preceding example, the radar is set for 40-mile range operation. The sweep circuits will thus operate *only* for an equivalent time interval, so that targets beyond 40 miles will not appear on the scope. The time equivalent to 40 miles of radar range is only 496 microseconds (0.000496 seconds). Thus, 496 microseconds (plus an additional period of perhaps 100 microseconds to allow the sweep circuits to recover) after a pulse is transmitted, the radar is ready to transmit the next pulse. The actual pulse repetition rate in this example is about 800 pulses per second. The return will therefore appear in virtually the same position along the sweep as each successive pulse is transmitted, even though the aircraft and the target are moving at appreciable speeds.

Measurement of Bearing

The deflection coils, illustrated in figure 10-2, are mounted so they surround the neck of the CRT. *The direction taken by the sweep corresponds directly to the orientation of the deflection coils.* In the previous discussion of range, it was assumed that the deflection coils were stationary, so that the sweep formed by the deflection current always fell along the same radial. However, if the antenna (which forms the transmitted energy into a narrow beam) is rotated slowly in azimuth and the deflection coils are rotated mechanically in synchronism with the antenna, the sweep trace will point in the same direction as the antenna. Therefore, the relative bearing, as well as the range, of reflecting objects will be shown on the scope.

Plan Position Indicator (PPI)

The type of cathode ray tube display just discussed is called a *plan position indicator (PPI)*. It presents a map-like picture of the terrain below and around the aircraft. This is the presentation usually available in radar-equipped aircraft. In figure 10-3, the center of the scope represents the aircraft radar antenna. A radar target is shown at its correct bearing and at a distance from the scope center proportional to its range. To facilitate the measurement of range, "false" echoes called *fixed range markers* are generated electrically at regular intervals after each transmitted pulse and introduced at the indicator in the same manner as the actual echoes.

Since these markers always appear at the same position on the sweep for a given range setting, they trace concentric range circles on the scope. On some radar sets, the range mark circles are traced at appropriate intervals, such as every 2 miles when maximum range is 5 or 10 miles, every 5 miles on the 30-mile scale, and every 25 miles on the 100- or 200-mile scales.

To facilitate the measurement of bearing, a compass rose surrounds the scope, providing a convenient bearing reference. On most sets, the bearing of any particular return may be determined by bisecting the return with a cursor (a radial line inscribed on a transparent overlay) which can be rotated manually about an axis coincident with the center of the scope. The corresponding bearing is then read on the compass rose at the periphery of the scope.

In the plan position indicator illustrated in figure 10-3, the range scale is 100 miles; the range marker interval is 25 miles. Thus, the large target shown is at a relative bearing of 060° at a range of 50 miles.

SCOPE INTERPRETATION

The plan position indicator presents a map-like picture of the terrain below and around the aircraft. Just as map reading skill is largely dependent upon the ability to correlate what is seen on the ground with the symbols on the chart; so "radar" skill is largely dependent upon the ability to correlate

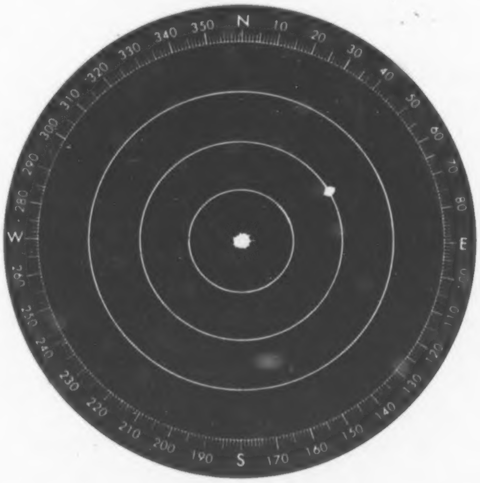


Figure 10-3. Plan Position Indicator (PPI)

what is seen on the scope with the chart symbols. Accordingly, a sound knowledge of the factors affecting radar reflection is a prerequisite to intelligent radarscope interpretation. Furthermore, a knowledge of these factors, applied in reverse, enables the navigator to *predict* the probable radarscope appearance of any area.

Factors Affecting Reflection

There are four primary factors which determine whether a usable portion of the transmitted energy will be reflected from a given object. No one factor, however, determines the amount of reflection; total reflection is based on a combination of all four factors. These factors are:

- Vertical and horizontal size.
- Material of the object.
- Radar range.
- Reflection angle.

VERTICAL AND HORIZONTAL SIZE. Assuming equal width, the *taller* of two structures presents the greater reflecting area. Its radar reflection potential is therefore greater.

Assuming equal height, the *wider* of two structures presents the greater reflecting area. This will cause it to appear as the larger return on the scope.

MATERIAL OF THE OBJECT. It is a basic law of physics that all substances reflect some electromagnetic energy. All substances also absorb some electromagnetic energy. Whether or not a substance may be considered a good radar reflector depends upon the ratio of the energy reflected to the energy absorbed. In general, this ratio depends primarily on the electrical conductivity of the substance. The reflection properties of the various materials from the best through the poorest are as follows:

Metals. Because of their high electrical conductivity, steel, iron, copper, aluminum, and most other metals are excellent reflectors of radio energy. A metal-clad building usually has high radar reflection potential. Those buildings which use steel or some other metal as structural reinforcement follow closely behind metal-clad buildings. This group includes concrete structures built around steel frameworks, commonly called "mixed" structures.

Water. Water is an excellent reflector of radio energy. However, an aircraft flying over a smooth water surface receives very little reflected energy from the surface because the angle of reflection is away from the aircraft. If the sea surface is not smooth, considerable energy is reflected resulting in large areas of *sea clutter* similar to *ground clutter.*

Masonry. Masonry by itself is a fair reflector. Masonry materials include stone, concrete, and clay products. However, masonry is often mixed with structural steel. These mixed structures have greater radar reflection potential than masonry alone.

Wood. In comparison to metal or masonry, wood is a poor reflector. Wooden structures do not normally reflect sufficient radar energy for display unless other important reflecting factors (such as unusual size) are present.

Dirt, Sand, and Stone. Although their reflection potential will vary to some extent with the particular chemical composition involved, dirt, sand, and stone are not normally considered good reflecting materials. Also, radar return from flat land areas is not nearly so great as that from land which exhibits irregular surfaces, such as sand dunes, hills, gravel pits, quarries, and similar prominences.

Glass. Glass by itself is not a good radar reflector. However, structures using glass walls usually have steel framing and such structures often can be considered among the better reflectors.

The diagram in figure 10-4 shows the relative reflection potential of the basic structural materials. These relationships will hold true, of course, only on the assumption that the other factors affecting reflection—size, range, and reflection angle—are equal.

RADAR RANGE. Range affects radar reflection in two ways. First, the *nearer* of two objects of equal size occupies a greater percentage of the beam width and so has more energy incident upon it. It will therefore appear as the brighter return. Second, as the radar waves travel through space, many minute particles of dust and other foreign matter intercept the beam. The resulting absorption decreases the strength of, or attenuates, the signal. The farther the energy travels, the more attenuation occurs. The attenuation effect is compensated for by automatic increase of the power output as the operating range is increased to the next higher increment.

REFLECTION ANGLE. In all cases of true reflection, the angle of reflection is equal to the

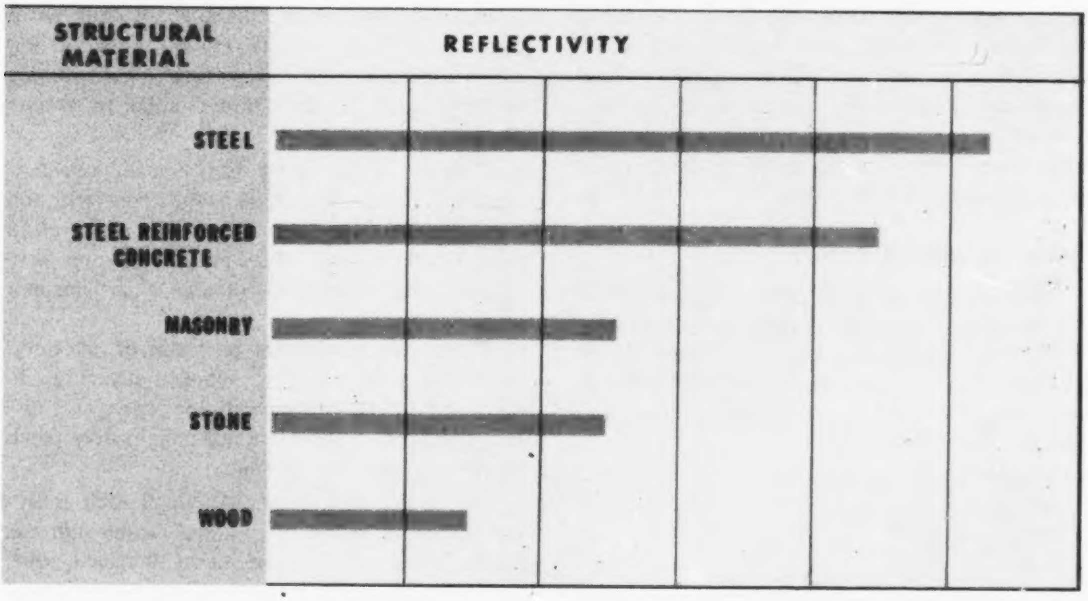


Figure 10-4. Relative Reflectivity of Structural Materials

angle of incidence. Therefore, maximum reflection back to a radar set occurs when the reflecting surfaces are at right angles to the radar beam. For this reason, flat surfaces can give a momentarily intense directional reflection, just as the windshield of an automobile does when it flashes in the sunlight. However, such radar echoes, though very strong, are normally not usable for navigational purposes because the brevity of their existence does not allow sufficient time for identification. Fortunately, the great majority of radar targets are multifaceted rather than smooth, so that at any given instant some part of the target will be at right angles to the beam. The more closely the incident wave approaches a direct right angle with respect to the overall surface, the greater will be the radar reflection.

Horizontal. The effect of the horizontal reflection angle is shown in figure 10-5. Because of the particular configuration between the aircraft and reflecting objects, the aircraft at *A* gets no return from building 1 and maximum return from building 2 and the railroad tracks. At *B*, the aircraft gets no reflection from building 2 and maximum reflection from the railroad tracks. At *C*, maximum reflection is again being obtained from building 2. This entire discussion oversimplifies the problem for purposes of clarity. It should be emphasized again that smooth surfaces such as those shown are rarely encountered, and for normal structures, the amount of reflection would be *minimum* where *zero* reflection has been implied.

Vertical. The effect of the vertical reflection angle is not nearly so pronounced as that of the horizontal reflection angle. This is because of the much greater beam width in the vertical dimension as compared to the horizontal when the normal mapping beam is used. The vertical beam width may be on the order of 50 degrees and the horizontal beam width on the order of 1½ degrees. The effect of the vertical reflection angle cannot, however, be neglected. Figure 10-6 shows that the vertical energy pattern contains a main lobe. To obtain maximum reflection, this main lobe should strike the overall reflecting surface at right angles to it. In most buildings, the overall reflecting surface is vertical. Thus, as an aircraft approaches a building or group of buildings, the actual vertical reflection angle becomes more and more removed from the optimum. The final result is that, when the vertical reflection angle approaches 45 degrees, many of the structures scanned by the beam do not reflect enough energy back to the set to appear on the scope (see figure 10-7). The zone in which this lack of reflection is likely to occur is equal in radius to the altitude of the aircraft. For example,

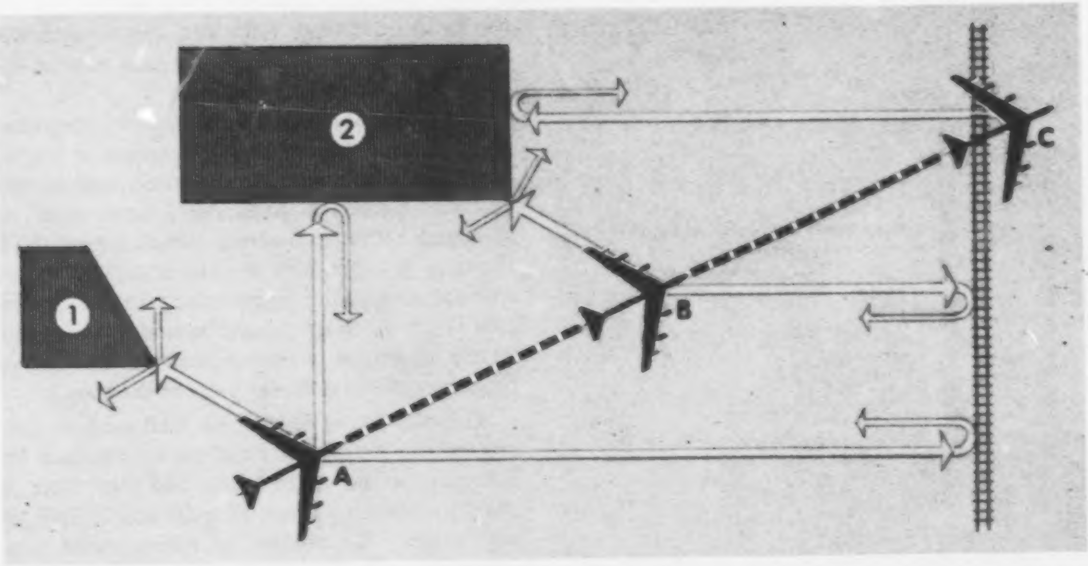


Figure 10-5. Horizontal Reflection Angle

an aircraft flying at extremely high altitudes might display only the returns from the very best types of reflectors—such as steel mills—in the area within eight or ten miles from the aircraft.

Adjustment of the antenna tilt control can compensate to a degree for the above effect. By tilting the antenna downward as the target is approached, more energy is made to strike the target at the optimum reflection angle. However, this reduces the overall coverage of the radar scan because the energy directed out ahead of the aircraft is reduced.

SUMMARY. It is important to re-emphasize that no one factor determines the reflection potential of a given reflector. However, a single factor may prevent sufficient reflection to create a return on the scope. The following general rules will apply:

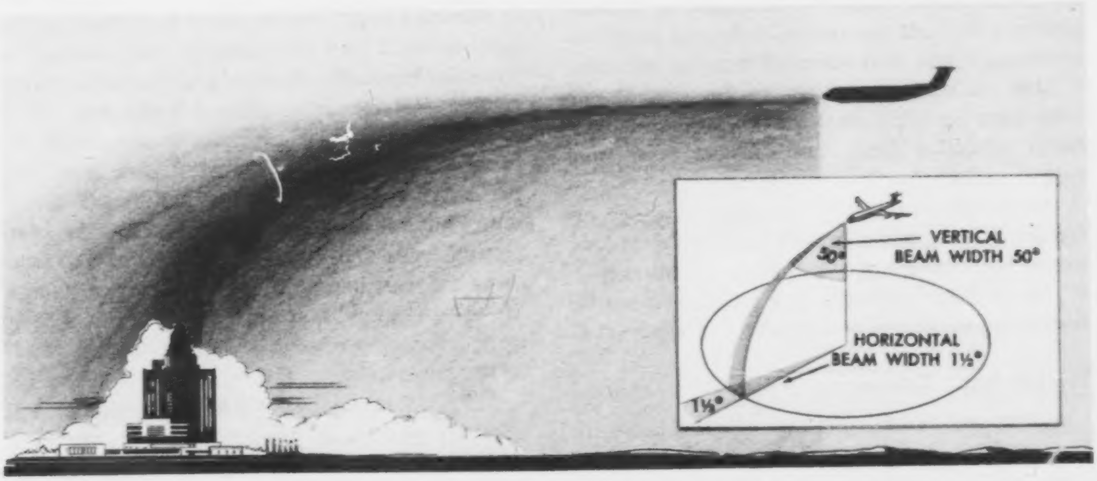


Figure 10-6. Radiation Pattern of Antenna

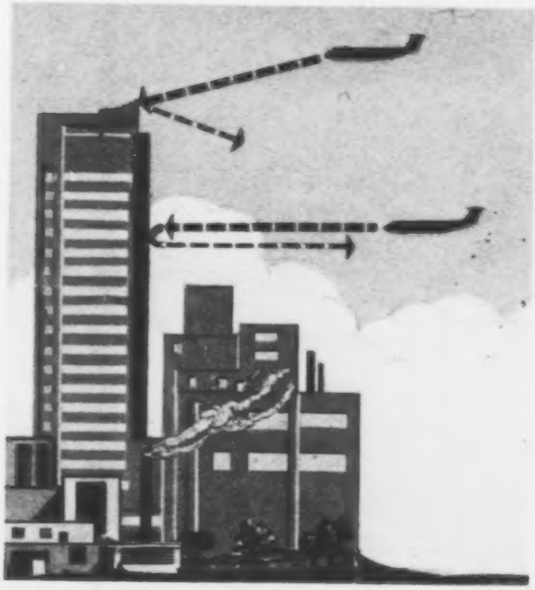


Figure 10-7. Vertical Reflection Angle Varies With Aircraft Position and Altitude

1. The greatest return potential exists when the radar beam forms a horizontal right angle with the frontal portion of the reflector.
2. Radar return potential is roughly proportional to structure size and the reflective properties of the construction material used.
3. Radar return potential is greatest within the zone of the greatest radiation pattern of the antenna, as illustrated in figure 10-6.
4. Radar return potential decreases as altitude increases because the vertical reflection angle becomes more and more removed from the optimum. (There are many exceptions to this general rule since there are many structures which may present better reflection from roof surfaces than from frontal surfaces.)
5. Radar return potential decreases as range increases because of the greater beam width at long ranges and because of atmospheric attenuation.
6. All of the factors affecting reflection must be considered to determine the radar return potential.

Typical Scope Returns

There are certain characteristics peculiar to returns from specific ground features such as rivers, lakes, mountains, railroads, cities, etc. To consolidate the knowledge of the general rules on the factors affecting reflection, this section describes and illustrates how these rules may be applied to specific ground features.

The principal problem in radarscope interpretation is finding the meaning of contrasts in brightness. This comes ahead of the purely navigational problem because a particular feature must be identified before it becomes useful. Figure 10-8 shows a representative ground area and its associated radarscope presentation. In the discussion which follows, it would be well to refer back to this illustration, noting in particular the relative brightness of the different parts of the scope.

RETURNS FROM LAND. All land surfaces present minute irregular parts of the total surface for reflection of the radar beam, and thus there is usually a certain amount of radar return from all land areas. The amount of return varies considerably according to the nature of the land surface scanned. This variance is caused by (1) the difference in reflecting materials of which the land area is composed, and (2) the texture of the land surface. These are the primary factors governing the total radar return from specific land areas.

Flat land. A certain amount of any surface, however flat in the overall view, is irregular enough to reflect the radar beam. Surfaces which are apparently flat are actually textured and may cause return on the scope. Ordinary soil absorbs some of the radar energy and thus the return that emanates from this type of surface is not strong. Ray *B* in figure 10-9 shows that flat land will reflect most of the energy away from the aircraft.

Plowed Fields. Plowed fields and other irregularly textured land areas present more surface to the radar beam than flat land and thus create more return. Returns from plowed fields may be a problem to the radar navigator because such returns are not readily identifiable, are often not persistent, and tend to confuse the overall radarscope interpretation problem. The returns from plowed fields and other irregularly textured land areas are most intense when the radar beam scans the upright furrows or similar features at a right angle. This type of return is exemplified by ray *F* in the illustration.

Hills and Mountains. Hills and mountains will normally give more radar return than flat land because the radar beam is more nearly perpendicular to the sides of these features. The typical return is a bright return from the near side of the

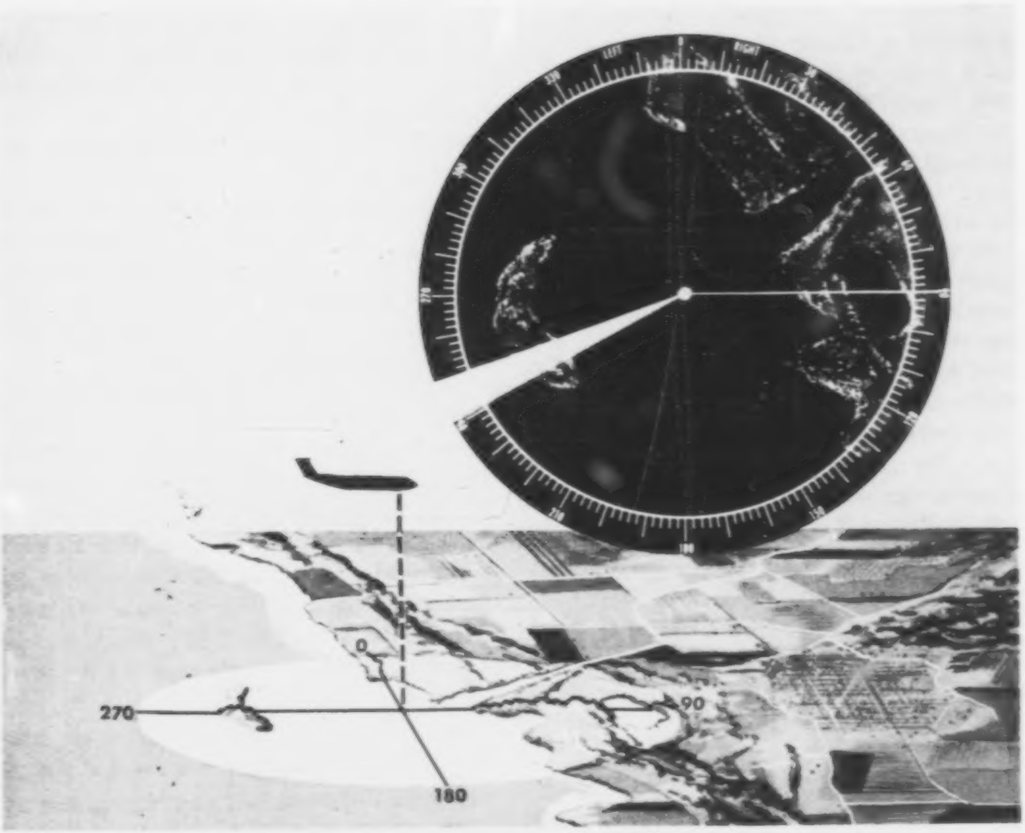

LEFT
RIGHT
0
270
90
180

Figure 10-8. Radar Returns

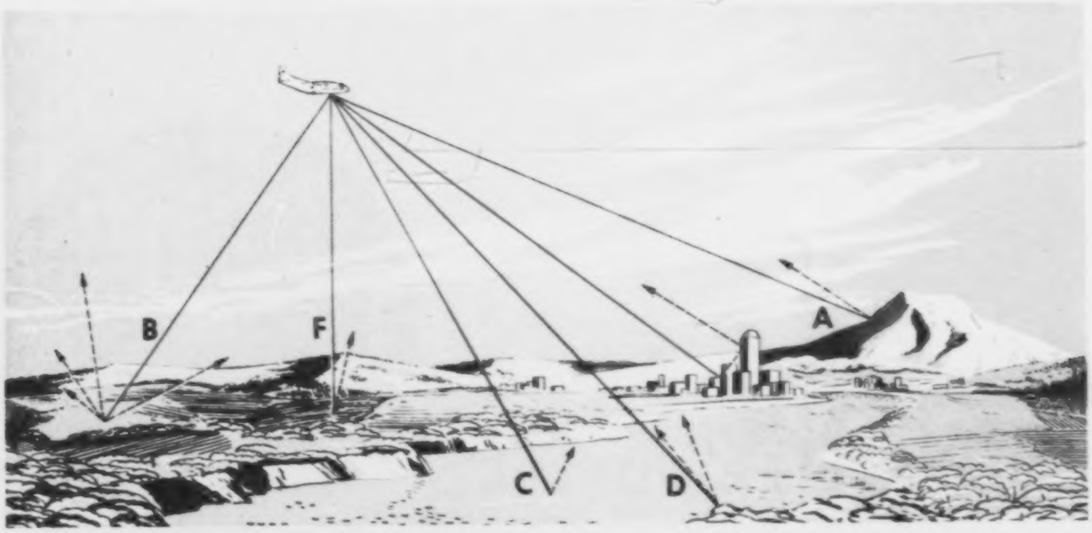


Figure 10-9. Reflections from Various Types of Terrain

feature and an area of no return on the far side. This is shown by ray *A*. The area of no return is called a mountain shadow and exists because the radar beam cannot pentrate the mountain, and its line-of-sight transmission does not allow it to intercept targets behind the mountain. The shadow area will vary in size, depending upon the height of the aircraft with respect to the mountain. As an aircraft approaches a mountain, the shadow area becomes smaller and smaller. Furthermore, the *shape* of the shadow area and the brightness of the return from the peak will vary as the aircraft's position changes.

Recognition of mountain shadow is important because any target in the area behind the mountain cannot be seen on the scope. A striking example of this is illustrated in figure 10-10. Note that the mountains obscure the area in which the town of Adams lies.

In areas with isolated high peaks or mountain ridges, contour navigation may be possible because the returns from such features assume an almost three-dimensional appearance. This allows specific peaks to be identified.

In more rugged mountainous areas, however, there may be so many mountains with resulting return and shadow areas that contour navigation is almost impossible. Note the complexity of the mountain returns in figure 10-11. In an area such as this, the radar might still be used for general orientation. For example, the aircraft is flying over the line of demarkation between a mountainous and a level area. This line of demarkation might serve as a *line of position* even though the complexity of the scope picture makes positive position finding impossible.

Coastlines and Riverbanks. The contrast between water and land is very sharp, so that the configuration of coasts and lakes are seen with map-like clarity. When the radar beam scans the banks of a river, lake, or larger body of water, there is little or no return from the water surface itself, but there is usually a strong return from the adjoining land. This may be seen from rays *C* and *D* in figure 10-9. The more rugged the bank or coastline, the more return will be experienced.

A nearby shoreline will be very clearly delineated when an aircraft is out over the adjoining water. However, the shoreline tends to lose its clearcut separation from the water when the aircraft is flying over the land. This is because the coastline presents upright banks to the overwater radar beam and relatively flat land to the overland beam. This also explains why the *far* side of a lake will appear brighter than the near side. Notice in figure 10-12 that the lake at 320° shows a much stronger return from the far side than from the near side.

Since both mountains and lakes present a "dark" area on the scope, it is sometimes fairly easy to mistake a mountain shadow for a lake.

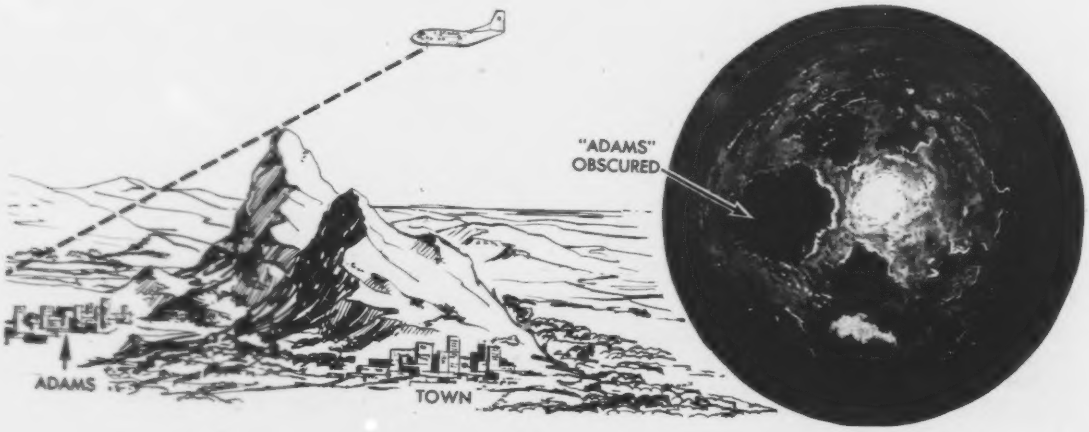


Figure 10-10. Significant Areas are Sometimes Obscured by Mountains

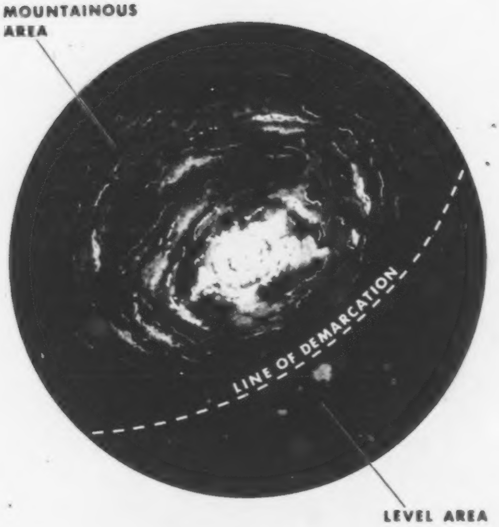


Figure 10-11. Individual Peaks are Difficult to Identify

This is particularly true when navigating in mountainous areas which also contain lakes.

The essential difference between returns from mountain areas and lakes is that returns from mountains are bright on the near side and dark on the far side; returns from lakes are bright on the far side and vague on the near side. Another characteristic of mountain returns is that the dark area changes shape and position quite rapidly as the aircraft moves, returns from lakes change only slightly.

URBAN AREAS. The overall size and shape of the radar return from any given city can usually be determined with a fair degree of accuracy by referring to a map of the area. However, the brightness of one urban area as compared to another may vary greatly, and this variance can hardly be forecast by reference to the navigation chart. In general, the industrial and commercial centers of cities and towns produce much greater brightness than the outlying residential areas.

ISOLATED STRUCTURES. Many isolated or small groups of structures create radar returns. The size and brightness of the radar returns these features give are dependent on their construction. Most of these structures are not plotted on the navigation charts; hence, they are of no navigational value. However, some of them give very strong returns—such as large concrete dams, steel bridges, etc.—and if they can be properly identified they give valuable navigational assistance.

GLITTER AND CARDINAL POINT EFFECT.

Glitter, Glitter or glint, is the cause of most fluctuating returns that appear on the scope. It occurs when the radar beam scans a relatively small reflector which is able to present sufficient reflection for display on the scope only when the radar beam is at right angles to the structure. Since the aircraft is moving, the conditions necessary for the display of such an object exist only momentarily; hence, the return appears only momentarily on the scope (see figure 10-13).

Cardinal Point Effect. This is glitter that occurs when the radar beam scans a large number of structures at right angles. In this case, the return may remain for more than the customary instant. Because most cities and towns are laid out along

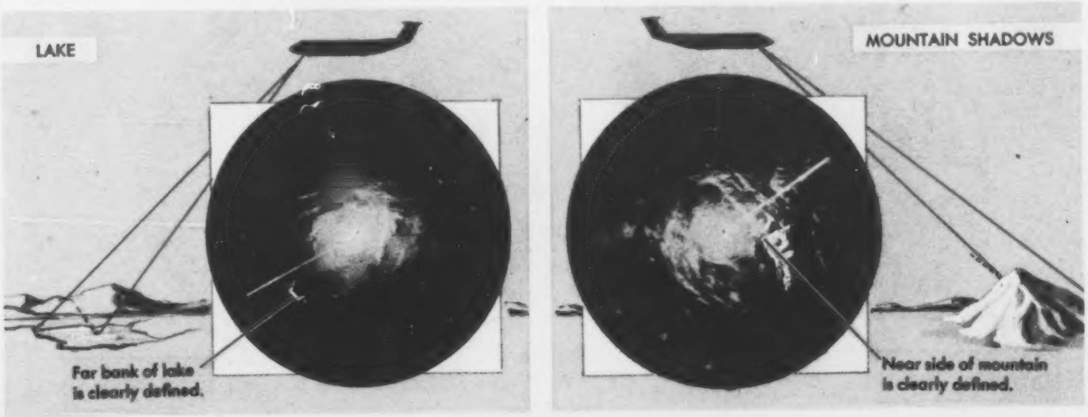
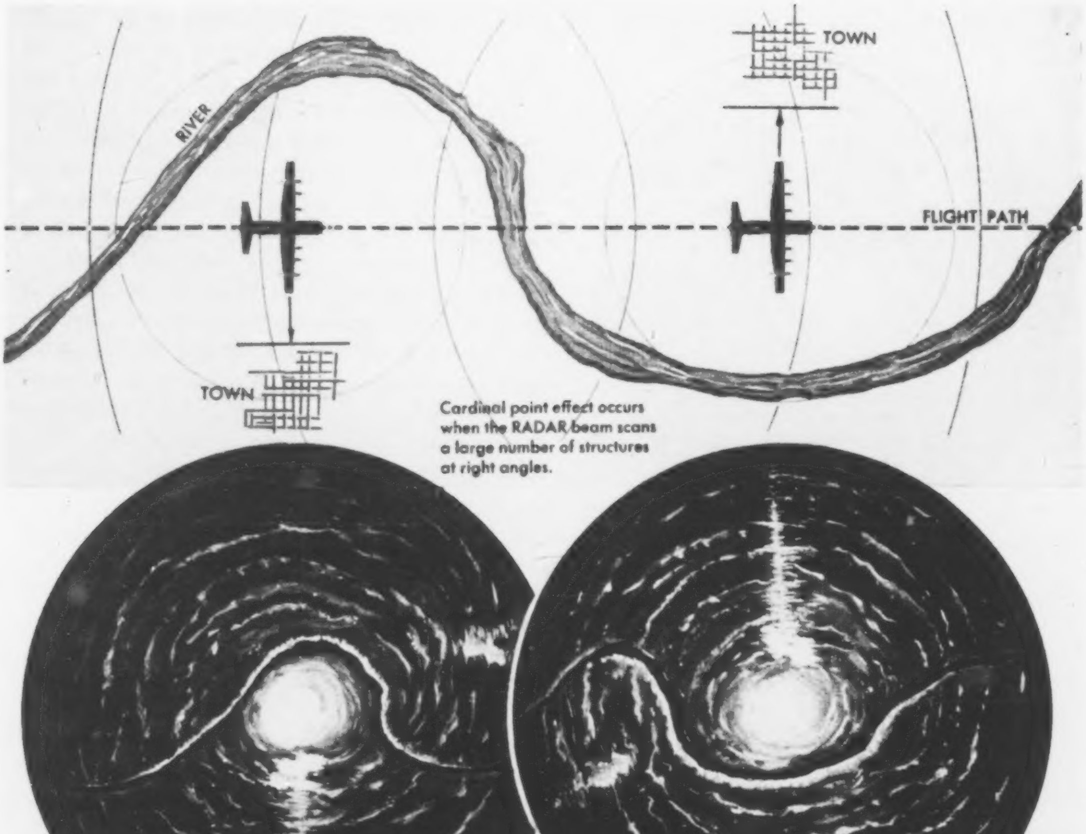

LAKE
Far bank of lake is clearly defined.
MOUNTAIN SHADOWS
Near side of mountain is clearly defined.

Figure 10-12. Mountains and Lakes



Cardinal point effect occurs when the RADAR beam scans a large number of structures at right angles.

RADAR return at 330°/22 NM has no cardinal point effect.

Same RADAR return now at 358°/26 NM has cardinal point effect.

10 NM FIXED RANGE MARKS

Figure 10-14. Cardinal Point Effect

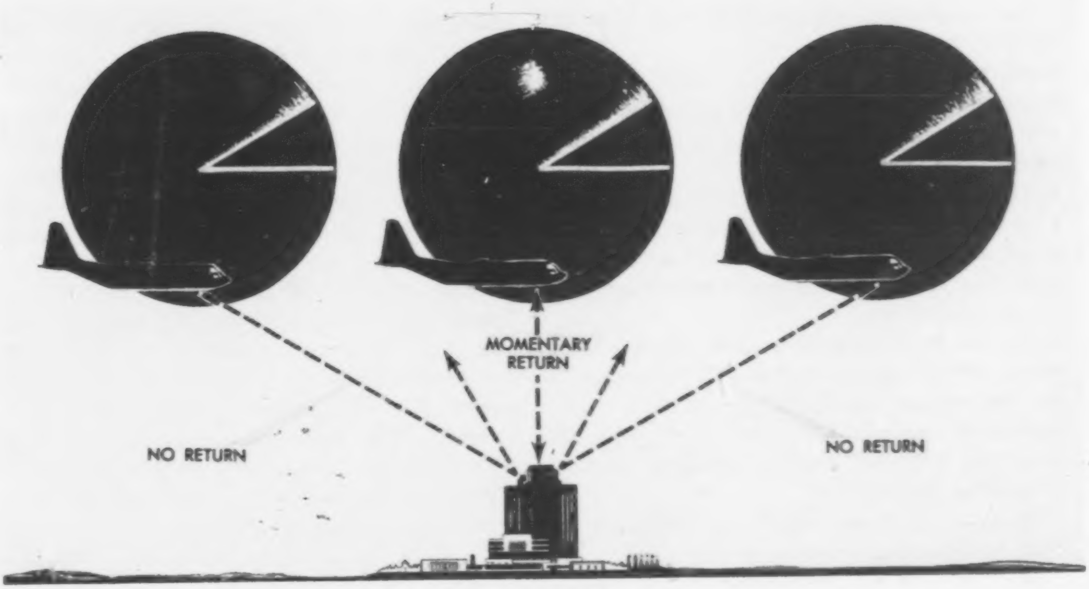


Figure 10-13. Glitter

north-south and east-west axes, cardinal point effect usually occurs when the true bearing of a city is equal to one of the cardinal directions. However, the effect can occur on any axis according to the particular geographical alignment involved. Cardinal point effect is illustrated in figure 10-14.

WEATHER RETURNS. Cloud returns which appear on the scope are called *precipitation or meteorological echoes.* They are of interest for two reasons. First, since the brightness of a given cloud return is an indication of the intensity of the weather within the cloud, intense weather areas can be avoided by directing the pilot through the darker scope areas or by completely circumnavigating the entire cloud return. Second, cloud returns obscure useful natural and cultural features on the ground. They may also be falsely identified as a ground feature, which can lead to gross errors in radar fixing.

Clouds must be reasonably large to create a return on the scope. However, size alone is not the sole determining factor. Cloud layers covering hundreds of square miles will not always create returns. As a matter of fact, clouds covering such wide areas rarely show on the scope. The one really important characteristic that causes clouds to create radar returns is the size of the water droplets forming them. Radar waves are reflected from large water droplets falling through the atmosphere as rain or suspended in the clouds by strong vertical air currents. Thunderstorms are characterized by strong vertical air currents; therefore, they give very strong radar returns (see figure 10-15).

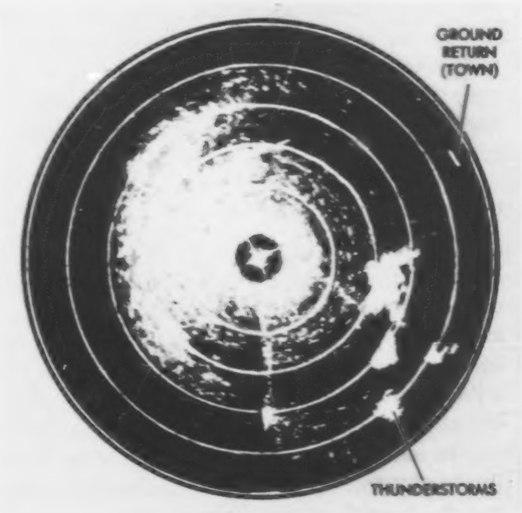


Figure 10-15. Thunderstorm Returns

Cloud returns may be identified by the following characteristics:

- Brightness varies considerably, but the average brightness is greater than normal ground return.
- Returns generally present a hazy, fuzzy appearance around their edges.
- Terrain features are not present.
- Returns often produce a shadow area similar to mountain shadow because the radar beam does not penetrate clouds with sufficient strength to create echoes beyond them.
- Returns do not fade away as the antenna tilt is raised, whereas ground returns tend to decrease in intensity with an increase in antenna tilt.
- Returns appear in the altitude hole when altitude delay is not used and the distance to the cloud is less than the altitude.

EFFECTS OF SNOW AND ICE. The effects of snow and ice, most prevalent in arctic regions, are similar to the effect of water. If a land area is covered to any great depth with snow, the radar beam will reflect from the snow rather than from the features which lie beneath. The overall effect is to *reduce* the return which would normally come from the snow-blanketed area.

Ice will react in a slightly different manner, depending upon its roughness. If an ice coating on a body of water remains smooth, the return will appear approximately the same as a water return. However, if the ice is formed in irregular patterns, the returns created will be comparable to terrain features of commensurate size. For example, ice ridges or ice mountains would create returns comparable to ground embankments or mountains, respectively. Also, offshore ice floes tend to disguise the true shape of a coastline so that the coastline may appear vastly different in winter as compared to summer.

Inherent Scope Errors

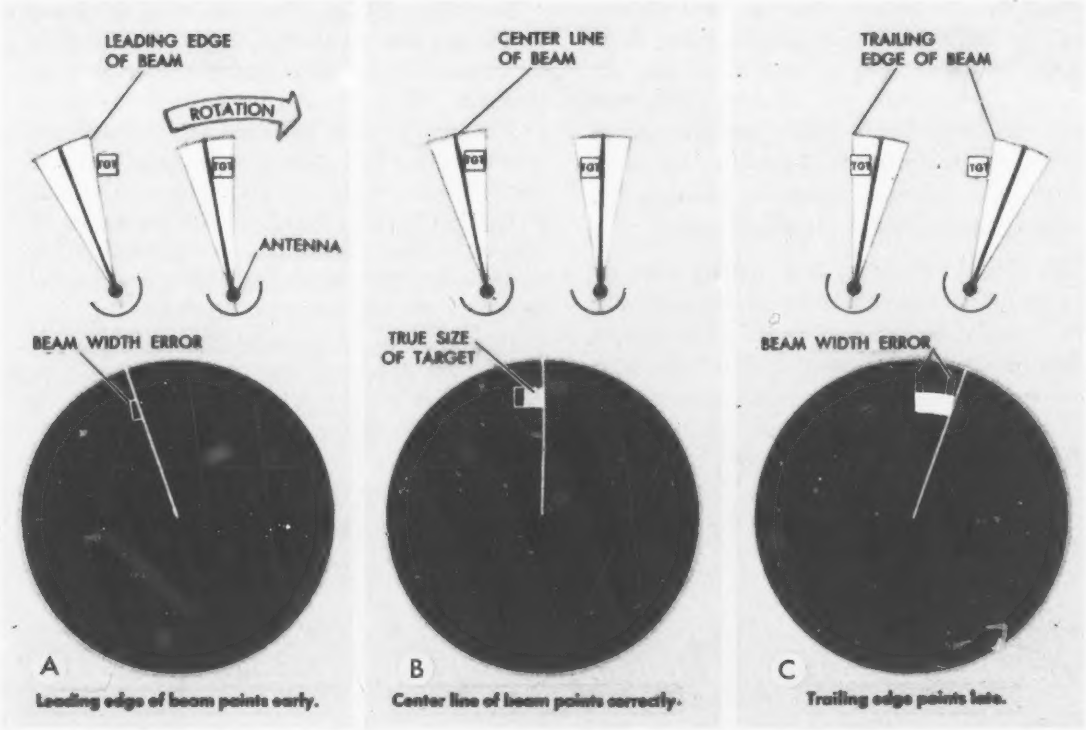
Another factor which must be considered in radarscope interpretation is the inherent distortion of the radar display. This distortion is present to a greater or lesser degree in every radar set, depending upon its design. It can be minimized by a proper understanding of its causes and by proper use of the radar controls. Inherent scope errors may be laid to three causes: the width of the beam, the length (time duration) of the transmitted pulse, and the diameter of the electron spot.

BEAM WIDTH ERROR. The magnitude of this error may be as great as the width of the radar beam. Suppose, for example, that an isolated structure, 1000 feet wide, is being scanned by a beam one and one-half degrees wide at a range of 20 miles. If the target is an excellent reflector, it will begin to create a return as soon as the leading edge of the beam contacts it, while the center of the beam is still half the beam width away. Similarly, the target continues to create a return until the trailing edge of the beam leaves it. Thus, the target appears too wide by half the beam width on either side, or by a total of one beam width. However, this is the maximum error that could occur. The beam seldom intercepts targets of such excellent reflective characteristics as to induce the maximum error. Also, the beam subtends less linear arc as the range decreases so that beam width error decreases with range.

Actually, beam width error is not overly significant in radar navigation (although it must be taken into account in radar bombing). Since the distortion is essentially symmetrical, it may be nullified by bisecting the return with the bearing cursor when bearing is measured. Beam width distortion is also lessened by reduction of the receiver gain control. The principle and effect of beam-width error on reflecting targets are illustrated in figures 10-16 and 10-17.

PULSE LENGTH ERROR. Pulse length error is caused by the fact that the radar transmission is not instantaneous but lasts for a brief period of time. Imagine a huge steel plate so large that no radar pulse can penetrate beyond it. Such a reflector has no range dimension, therefore, the return on the scope should have no range dimension. However, if the pulse emitted by the radar transmitter is of one microsecond duration, this pulse will continue to strike the steel plate for one microsecond. It is obvious, then, that the target will reflect energy throughout this period of time, and a return will be displayed on the scope throughout this period. Since time is translated into distance on the scope face (1 microsecond equals 490 feet) and corrected for a radar mile, the target will appear to be approximately 490 feet longer than it actually is. Thus, there is a distortion in the range direction on the far side of the reflector, and this pulse length error is equal to the range equivalent of one-half the pulse time.

Since pulse length error occurs on the far side of the return as shown in figure 10-18, it may be

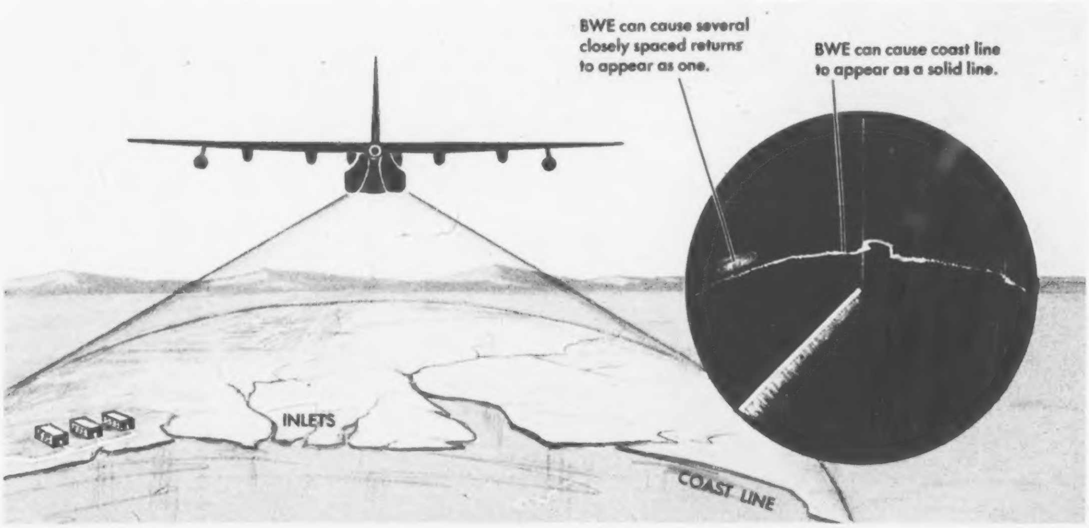

LEADING EDGE OF BEAM
ROTATION
TGT
TGT
ANTENNA
BEAM WIDTH ERROR
A
CENTER LINE OF BEAM
TGT
TGT
TRUE SIZE OF TARGET
B
TRAILING EDGE OF BEAM
TGT
TGT
BEAM WIDTH ERROR
C

Leading edge of beam points early.

Center line of beam points correctly.

Trailing edge points late.

Figure 10-16. Beam Width Error


INLETS
COAST LINE

BWE can cause several closely spaced returns to appear as one.

BWE can cause coast line to appear as a solid line.

Figure 10-17. Effect of Beam Width Error

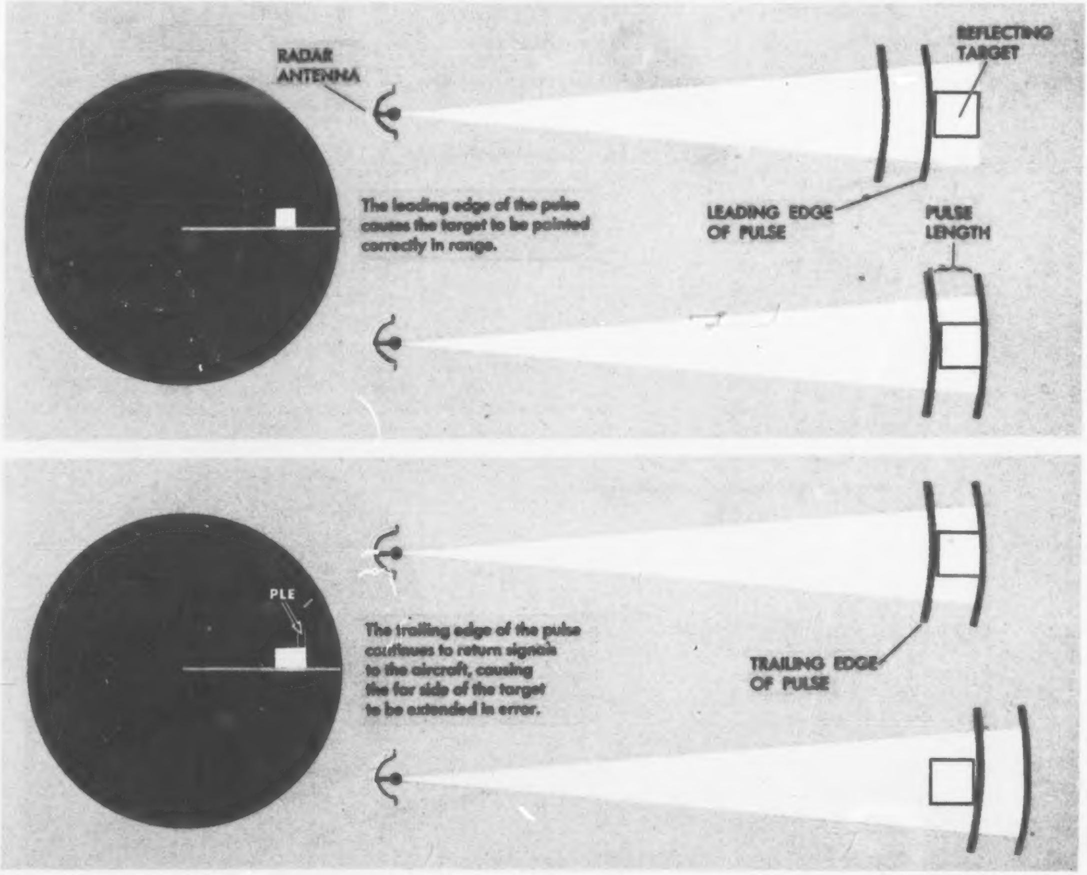
nullified by reading the range to (and plotting from) the near side of the target when taking radar ranges. It should also be mentioned that the radar set is so designed that the pulse length (and hence the pulse length error) increases as the operating range increases. Therefore, failure to employ the proper range measuring technique will produce greater errors at the longer ranges.

The pulse length also has a primary effect on the *range resolution* of a radar set. Theoretically, two sharply defined targets at the same bearing should be resolved into two separate returns on the scope if their ranges differ by the distance light travels during one-half the pulse length. Thus, with a one microsecond pulse length, two targets would have to be more than 490 feet apart in range to appear as two separate returns on the scope. (See figure 10-19.)

SPOT SIZE ERROR. Spot size error is caused by the fact that the electron beam which displays the returns on the scope has a definite physical diameter. No return which appears on the scope can be smaller than the diameter of the beam. Furthermore, a part of the glow produced when the electron beam strikes the phosphorescent coating of the CRT radiates laterally across the scope. As a result of these two factors, all returns displayed on the scope will appear to be slightly larger in size than they actually are. (See figure 10-20.)

Here again, as in the case of pulse length and beam width distortions, the effect is to reduce the *resolution* of the set. This may make it difficult for the radar navigator to isolate and identify returns.

Spot size distortion may be reduced by using the lowest practicable receiver gain, video gain, and bias settings and by keeping the operating



The leading edge of the pulse causes the target to be painted correctly in range.

The trailing edge of the pulse continues to return signals to the aircraft, causing the far side of the target to be extended in error.

Figure 10-18. Pulse Length Error

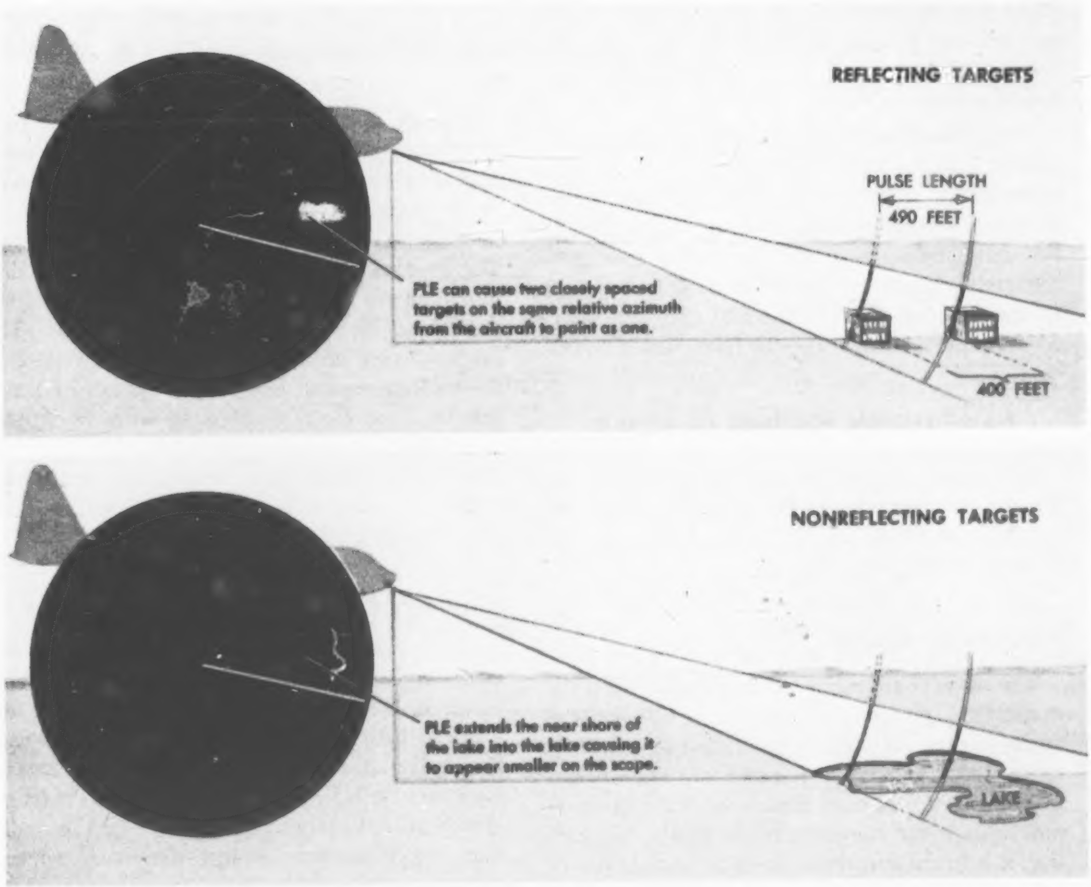

REFLECTING TARGETS
PULSE LENGTH
490 FEET
PLE can cause two closely spaced targets on the same relative azimuth from the aircraft to paint as one.
400 FEET
NONREFLECTING TARGETS
PLE extends the near shore of the lake into the lake causing it to appear smaller on the scope.
LAKE

Figure 10-19. Effect of Pulse Length Error

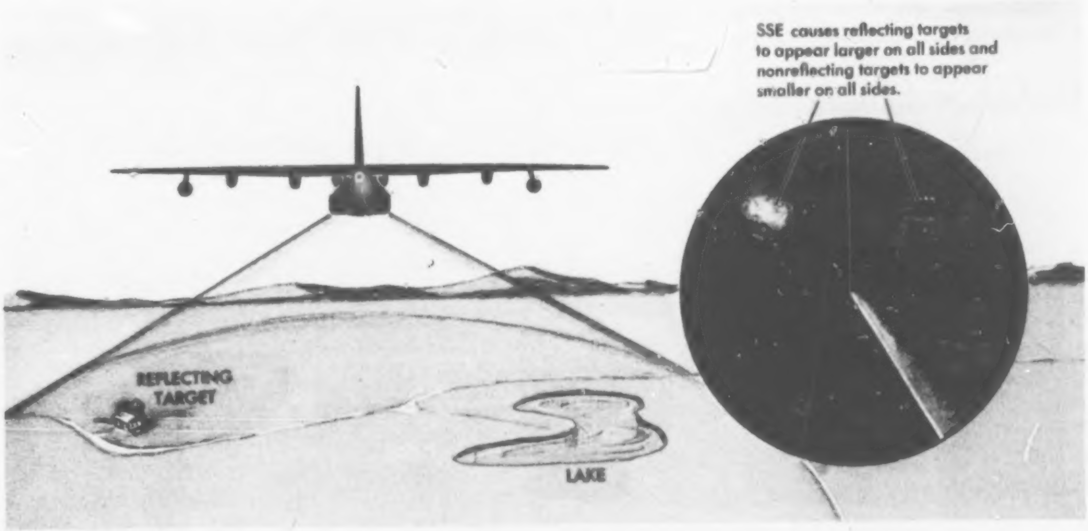

SSE causes reflecting targets to appear larger on all sides and nonreflecting targets to appear smaller on all sides.
REFLECTING TARGET
LAKE

Figure 10-20. Effect of Spot Size Error

range at a minimum so that the area represented by each spot is kept at a minimum. Further, the operator should check the focus control for optimum setting.

TOTAL DISTORTION. The radar presentation is distorted by three inherent errors: pulse length, beam width, and spot size. The combined effect of these errors is illustrated in figure 10-21. For navigational purposes, the errors are often negligible. However, the radar navigator should realize that they do exist and that optimum radar accuracy demands that they be taken into account.

NAVIGATIONAL FEATURES OF RADAR

The airborne radar sets used throughout the Air Force vary slightly in the navigational refinements offered. All of the sets in use, however, possess some of the following features.

Radar Range Selection

The range of any radar system depends upon the transmitted power, the receiver sensitivity, the antenna gain, and the various factors affecting reflection. However, since radar is a line-of-sight instrument, the ultimate limitation on the range of any radar is the curvature of the earth. In practice, it is found that the horizontal stratification of the atmosphere causes refraction of the microwave rays, usually bending them downward so that they tend to follow the curvature of the earth. This results in a theoretical radar range which may be determined by the following formula:

$$D = \sqrt{2h} \times .87$$

when D is nautical miles and h is the altitude in feet.

Though it is possible to receive returns from objects at great distances, it is not always necessary or desirable to have the maximum range portrayed on the scope. Therefore, the operating range of all radar sets can be controlled by the operator. The various sets differ as to the maximum and minimum ranges obtainable. Most sets currently in use may be varied from 3 to 400 miles. The range selected determines the comparative size of the various returns, and proper use of the range selector control can simplify the scope interpretation problem. For example, decreasing range will show a particular area in much greater detail, while increasing range (altitude permitting) will give a much greater coverage.

Fixed Range Markers

Fixed range markers have already been discussed under the heading, Plan Position Indicator. These markers describe concentric circles on the scope at fixed range intervals. They may be used to measure the *slant range* (the direct line-of-sight range) to any return appearing on the scope. It is often necessary to interpolate when using the fixed range markers because the return appears between two markers. On some sets, one of the several range intervals available—2, 5, 10, etc.—may be arbitrarily selected. On other sets, the range mark interval is automatically determined by the setting of the range selector control.

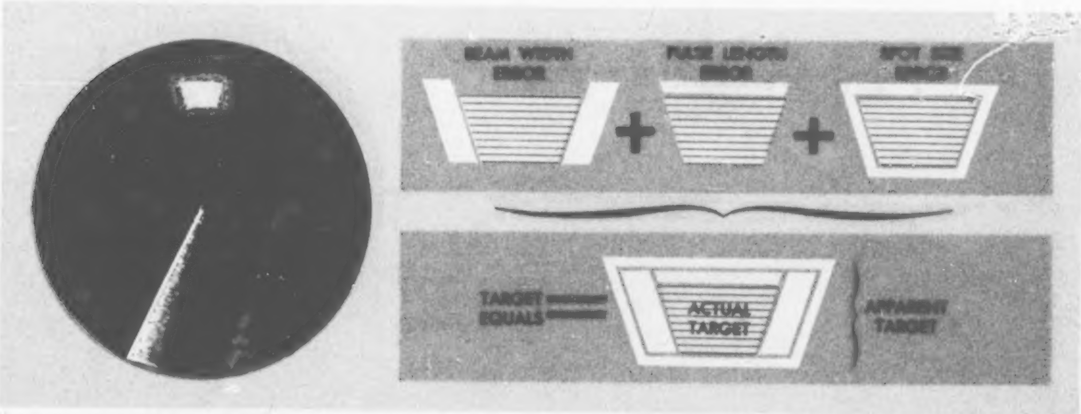


Figure 10-21. Combined Effect of Inherent Errors

Variable Range Marker and Crosshairs

Most radar sets also provide a range marker which may be moved within certain limits by the radar operator. This variable range marker permits more accurate measurement of range because the marker can be positioned more accurately on the scope. Furthermore, visual interpolation is not necessary when using the variable range marker because it can be placed at the particular return being considered.

On many radar sets, an electronic *azimuth marker* has been added to the variable range marker to facilitate fixing. The intersection of the azimuth marker and the variable range marker is defined as the *radar crosshairs.*

Azimuth Stabilization

To preclude the necessity for converting relative bearings to true bearings, a system has been devised which orients the scope so that true north always appears at the top. This system, known as *azimuth stabilization,* is so connected to the compass system that the sweep assumes the "12 o'clock" position when the antenna is pointed north, if the correct variation is set into the radar. An electronic *heading marker* indicates the true heading of the aircraft, and all bearings taken are *true bearings.* With the azimuth stabilization system off, the top of the scope represents the heading of the aircraft and all bearings taken are *relative* bearings. Figure 10-22 shows the visible

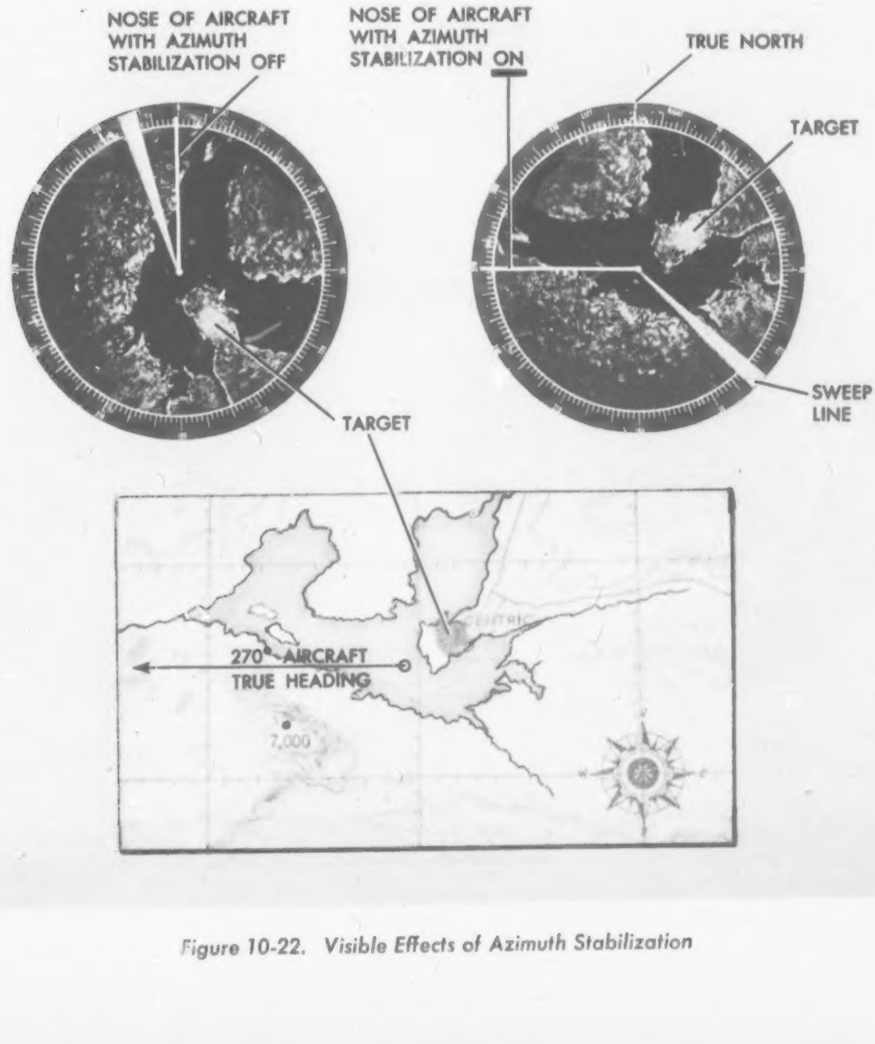

NOSE OF AIRCRAFT WITH AZIMUTH STABILIZATION OFF
NOSE OF AIRCRAFT WITH AZIMUTH STABILIZATION ON
TRUE NORTH
TARGET
SWEEP LINE
TARGET
CENTRIC
270° AIRCRAFT TRUE HEADING
7,000

Figure 10-22. *Visible Effects of Azimuth Stabilization*

effects of azimuth stabilization. The azimuth stabilization should be used at all times except in those regions where the tie-in to the compass system is impractical because of rapid changes in variation (as in polar areas).

Bearing Correction. For optimum accuracy, it may sometimes become necessary to correct the bearings taken on the various targets. This necessity arises whenever: (1) the heading marker reading does not agree with the true heading of the aircraft when azimuth stabilization is used, or (2) the heading marker reading does not agree with 360° when azimuth stabilization is not used.

Example. If the TH is 125° and the heading marker reads 120°, all of the returns on the scope will indicate a bearing which is 5° *less* than it should be. Therefore, if a target indicates a bearing of 50°, 5° must be *added* to the bearing before it is plotted. Conversely, should the heading marker read 45° when the TH is 040°, all of the scope returns will indicate a bearing which is 5° *more* than it should be. Therefore, if a target indicates a bearing of 275°, 5° must be *subtracted* from the bearing before it is plotted. The greater the distance of the target from the aircraft, the more important this *heading marker correction* becomes.

Altitude Delay

It is obvious that the ground directly beneath the aircraft is the closest reflecting object. Therefore, the first return which can appear on the scope will be from this ground point. Since it takes some finite period of time for the radar pulse to travel to the ground and back, it follows that the sweep must travel some finite distance radially from the center of the scope before it displays the first return. Consequently, a *hole* will appear in the center of the scope within which no ground returns can appear. Since the size of this hole is proportional to altitude, its radius can be used to measure altitude. Thus, if the radius of the *altitude hole* is 12,000 feet, the absolute altitude of the aircraft is 12,000 feet.

Although the altitude hole may be conveniently used to measure altitude, it occupies a large portion of the scope face, especially when the aircraft is flying at a high altitude and using a short range. This may be seen in figure 10-23. In this particu-

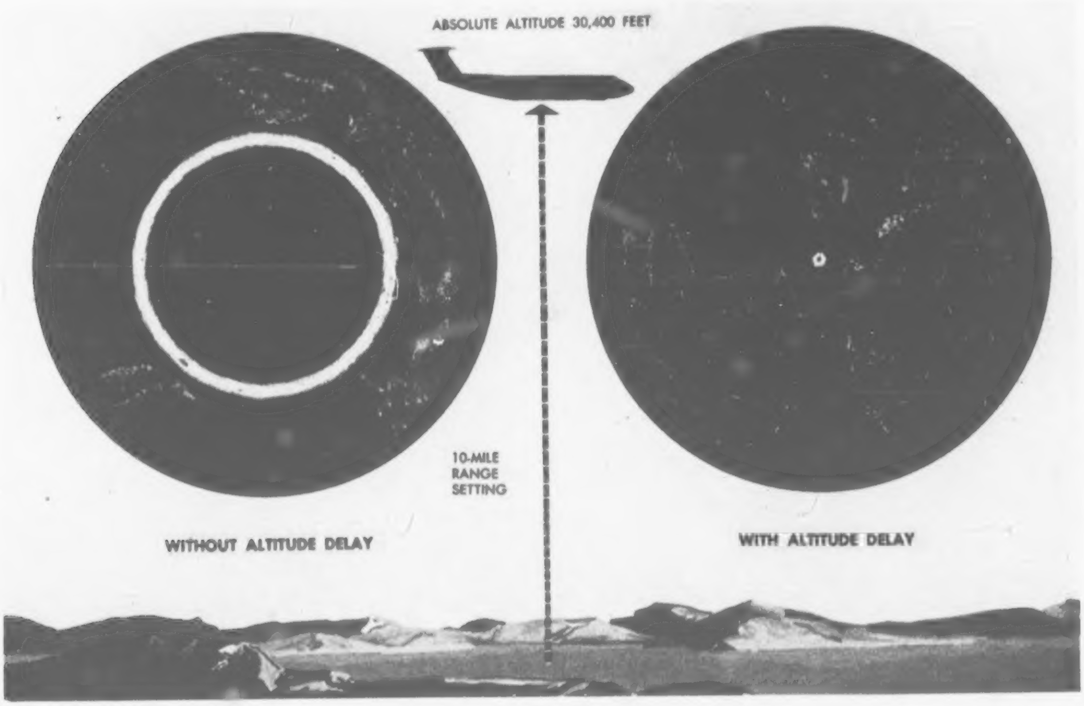


Figure 10-23. Altitude Delay Eliminates the Hole

lar case, the range selector switch is set for a 10-mile range presentation. Without altitude delay, the return shown on the first five miles of the scope consists of the altitude hole, and the return shown on the remaining five miles is a badly distorted presentation of *all of the terrain within ten miles of the point below the aircraft*. To obviate such a condition, many radar sets incorporate an *altitude delay circuit* which permits the removal of the altitude hole. This is accomplished by delaying the start of the sweep until the radar pulse has had time to travel to the ground point directly below the aircraft and back. Hence, the name altitude *delay* circuit. The altitude delay circuit also minimizes distortion of the type shown in the left-hand scope of figure 10-23. On this scope, it is evident that the area displayed is a greatly compressed version of the actual ground area. The circuit makes it possible for the radarscope to present a *ground picture*, which preserves the actual relationships between the various ground objects.

Sweep Delay

Sweep Delay is a feature which delays the start of the sweep until after the radar pulse has had time to travel some distance into space. In this respect, it is very similar to altitude delay. The use of sweep delay enables the radar operator to obtain an enlarged view of areas at extended ranges.

For example, two targets which are 45 miles from the aircraft can only be displayed on the scope if a range scale *greater* than 45 miles is being used. On the 50-mile range scale, the two targets might appear very small and close together. By introducing 40 miles of sweep delay, the display of the two targets will be enlarged *as long as the range displayed on the scope is less than that displayed before sweep delay was introduced*. For instance, if the scope is on a 50-mile range scale, as in the preceding example, introducing 40 miles of sweep delay would have no enlarging effect

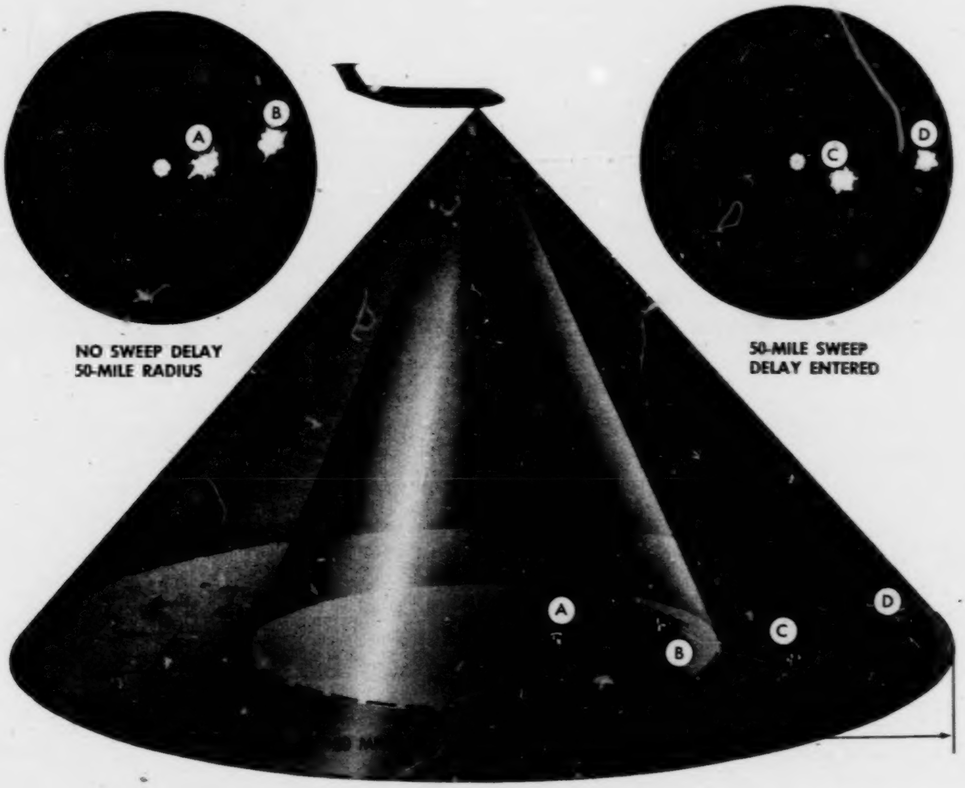


Figure 10-24. Sweep Delay Provides Telescopic View

unless the range being displayed is reduced to some value below 50 miles. The more this range is reduced, the greater will be the enlarging effect. On some sets, the range displayed during sweep delay operation is fixed by the design of the set and cannot be adjusted by the operator. Figure 10-24 shows graphically the effect of sweep delay.

RADAR FIXING

Each radar set in current use may provide methods of fixing which are peculiar to that set. If would be impossible to describe all of these methods. Therefore, only the basic methods employed with most sets are discussed here.

Measuring Range

Most radar sets offer a choice between the use of fixed range markers or a variable range marker for the measurement of range.

FIXED RANGE MARKERS. The fixed range markers are separated by specific intervals. These intervals are governed either by a range mark interval selector switch or by the range selector switch. In either case, the range marker interval must first be known before the markers can be used. Next, the position of the radar return with respect to the range markers is determined. Interpolation will often be necessary; thus, certain limits are imposed on the accuracy of this range measurement.

Slant Range. Once a return has been identified, it may be used to fix the position of the aircraft by measuring its bearing and distance from the known geographic point. Of particular significance in any discussion of radar ranging is the subject of slant range versus ground range. Slant range is the straight-line distance between the aircraft and the target, while ground range is the range between the point on the earth's surface directly below the aircraft and the target. Figure 10-25 shows how these two ranges may differ, and how the difference becomes less as the slant range increases. Figure 10-26 is a slant range/ground range table for various altitudes and ranges.

To fix the position of the aircraft, the navigator is interested in his *ground range* from the fixing point. Yet his fixed range markers give him slant range. His problem, then, is to determine the critical range below which he must convert slant range to ground range in order not to introduce significant errors in his fixes. This critical range may be determined by a simple formula:

$$\frac{\textit{Absolute Altitude} - 5{,}000}{1{,}000} = \textit{Critical slant range (in NM)}$$

Example:

$$\frac{30{,}000\ (\textit{Absolute Altitude in feet}) - 5{,}000}{1{,}000} = 25\ \textit{NM}$$

In this example, if the slant range is *less* than 25 miles, it should be converted to ground range before the fix is plotted. At ranges in excess of 25 miles, slant range would so closely approximate

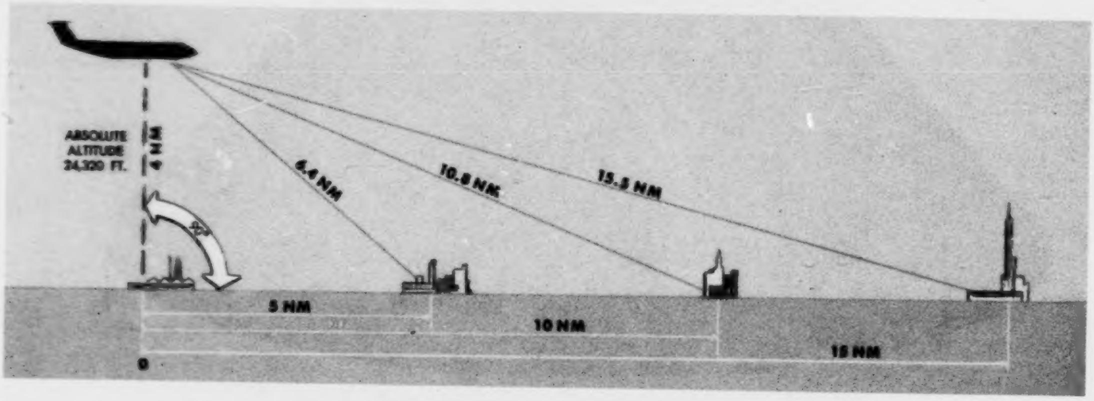


Figure 10-25. Slant Range Compared to Ground Range

Absolute Altitude Thousands of feet)	SLANT RANGE							
	5NM	10NM	15NM	20NM	25NM	30NM	35NM	40NM
	CORRESPONDING GROUND RANGE (NM)							
13	4.5	9.8	14.9	19.9	24.9	29.9	34.9	40.0
14	4.5	9.8	14.8	19.9	24.9	29.9	34.9	39.9
15	4.4	9.7	14.8	19.9	24.9	29.9	34.9	39.9
16	4.2	9.6	14.8	19.8	24.9	29.9	34.9	39.9
17	4.1	9.6	14.7	19.8	24.8	29.9	34.9	39.9
18	4.0	9.5	14.7	19.8	24.8	29.9	34.9	39.9
19	3.9	9.5	14.7	19.8	24.8	29.8	34.9	39.9
20	3.7	9.4	14.6	19.7	24.8	29.8	34.8	39.9
21	3.6	9.4	14.6	19.7	24.8	29.8	34.8	39.9
22	3.5	9.3	14.6	19.7	24.7	29.8	34.8	39.8
23	3.3	9.3	14.5	19.7	24.7	29.8	34.8	39.8
24	3.0	9.2	14.5	19.6	24.7	29.7	34.8	39.8
25	2.8	9.1	14.4	19.6	24.7	29.7	34.8	39.8
26	2.5	9.0	14.4	19.5	24.6	29.7	34.7	39.8
27	2.2	8.9	14.3	19.5	24.6	29.7	34.7	39.8
28	2.0	8.9	14.3	19.5	24.6	29.7	34.7	39.7
29	1.5	8.8	14.2	19.4	24.5	29.6	34.7	39.7
30	.8	8.7	14.2	19.4	24.5	29.6	34.7	39.7
31		8.6	14.1	19.3	24.5	29.6	34.6	39.7
32		8.5	14.1	19.3	24.4	29.5	34.6	39.6
33		8.4	14.0	19.2	24.4	29.5	34.6	39.6
34		8.3	13.9	19.2	24.4	29.5	34.6	39.6
35		8.2	13.9	19.1	24.3	29.4	34.5	39.6
36		8.1	13.8	19.1	24.3	29.4	34.5	39.6
37		7.9	13.7	19.0	24.2	29.4	34.5	39.5
38		7.8	13.6	19.0	24.2	29.3	34.4	39.5
39		7.7	13.6	18.9	24.2	29.3	34.4	39.5
40		7.5	13.5	18.9	24.1	29.3	34.4	39.5
41		7.4	13.4	18.8	24.1	29.2	34.4	39.4

Figure 10-26. Slant Range/Ground Range Table

ground range that conversion would be unnecessary.

Computer Method of Slant Range Conversion. Slant range may be converted to ground range on the hand-held computer by constructing the right triangle of ground range, slant range, and altitude as follows:

1. Convert the absolute altitude from feet to nautical miles by dividing by 6,080.
2. Set the computer azimuth with the index on a cardinal heading.
3. Using the wind side of the slide, measure down from the grommet the amount of the absolute altitude in nautical miles. This is shown in figure 10-27 where a scale of 10 on the computer is equal

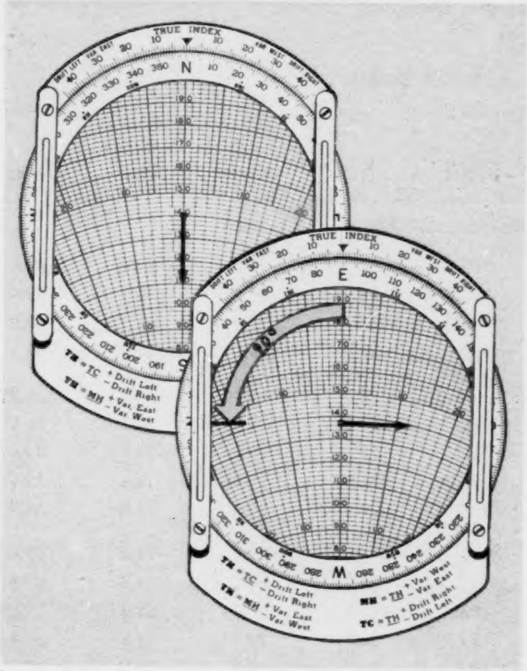

TRUE INDEX
N
E
S
W
TH = TC + Drift Left − Drift Right
TH = MH + Var. East − Var. West
MH = TH − Var. East + Var. West
TC = TH + Drift Right − Drift Left
30°

Figure 10-27. Computer Method of Slant Range Conversion

to one mile and the absolute altitude is three miles.

4. Rotate the computer 90° to another cardinal heading as in the illustration.

NOTE: Slant range is represented by a groundspeed line on the computer slide. For instance, if the slant range is 14 nautical miles, use the 140 groundspeed line.

5. Adjust the slide so that the correct groundspeed line is under the *outer end* of the plotted altitude vector, as in the illustration.

6. Read the ground range under the grommet.

7. Divide by 10 for the actual ground range.

Variable Range Marker. The variable range marker or crosshair is used for more precise measurement of position. The marker is placed on a selected radar return, and the position of the aircraft with respect to that return is indicated on a separate dial or dials. The indicated range is the ground range if the radar set is equipped with a computer and the absolute altitude of the aircraft is known and used in the computer. A limitation on the use of the variable range marker is the fact that the maximum range of the marker is far less than the ranges available using the fixed range markers. Fixes obtained using the radar crosshairs are called *precision fixes.*

Single Range and Bearing Fix

The single range and bearing fix is the method most widely used to obtain radar fixes. This fix is just what the name implies. The bearing of the return is measured on the calibrated azimuth ring or by using the electronic azimuth marker. If azimuth stabilization is off and the top of the scope represents the nose of the aircraft, this bearing is a relative bearing and must be added to the true heading in order to obtain a true bearing. If azimuth stabilization is on and the proper variation is set, the bearing measured is true bearing and may be plotted as such. (The heading marker correction must, of course, be applied to all bearings taken). The reciprocal of the bearing to the radar target becomes a line of position which is crossed with the range measurement to obtain a fix (see figure 10-28).

Multiple Bearing Fix

Sometimes it is not possible to measure range with the radar. When this occurs, accurate fixes are obtained by crossing azimuth bearings from two or more identified targets. The best results are obtained when using three targets 120° apart. If only two targets are used, 90° cuts give the best results. The three-bearing fix, of course, is generally more accurate.

The following is one method of taking a multiple bearing fix:

1. Identify three returns approximately 120° apart.
2. Using the bearing cursor, take the bearing of each return in quick succession.
3. Note the time of the bearings.
4. Plot the reciprocals of the bearings on the chart as shown in figure 10-29.

The intersection of the bearing lines is the radar fix. The time of the fix is the time noted in step three.

Multiple Range Fixes

If the scale illumination light is burned out, the cursor cannot be moved, or if the scope presentation cannot be centered on the cursor plate, it would be necessary to position the aircraft by multiple range fixes derived by measuring the range to two or more targets and plotting these

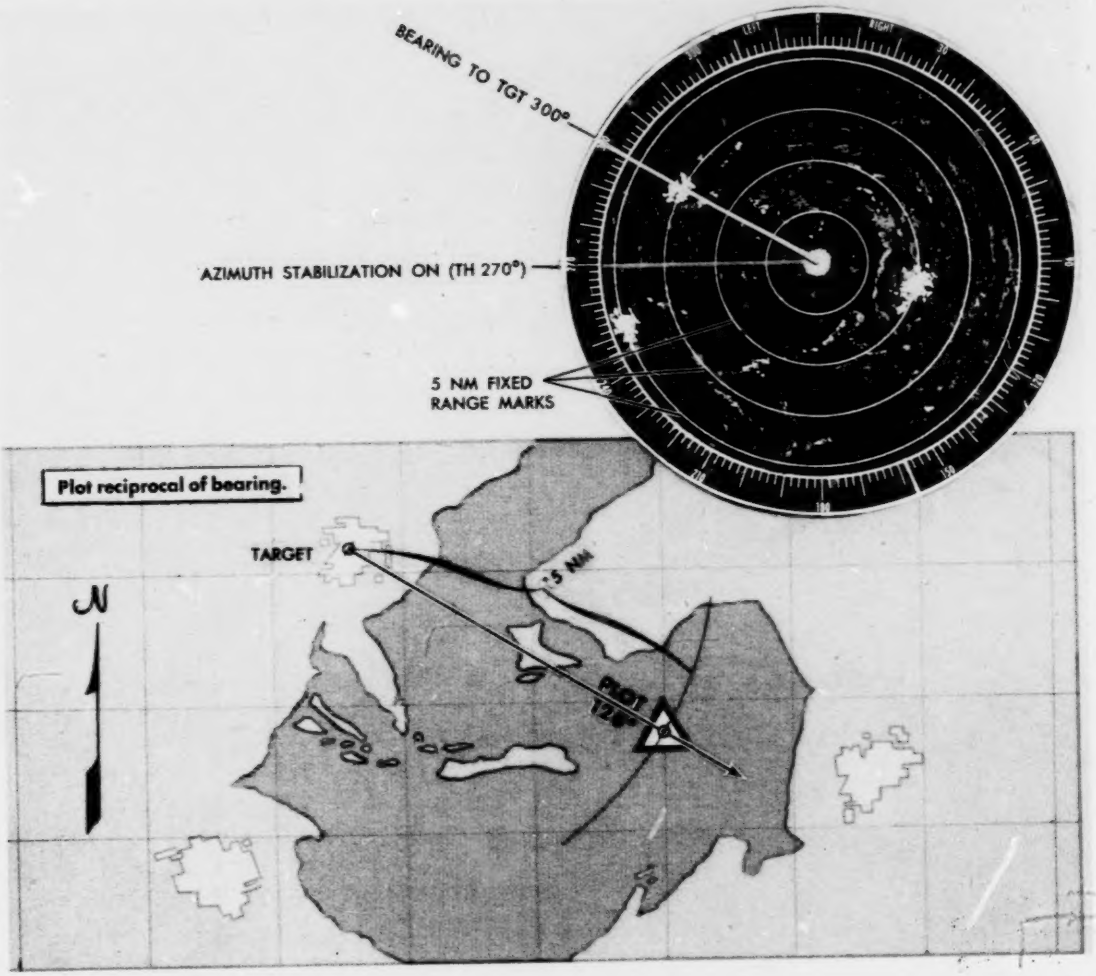

BEARING TO TGT 300°
AZIMUTH STABILIZATION ON (TH 270°)
5 NM FIXED RANGE MARKS
Plot reciprocal of bearing.
TARGET
5 NM
N
PLOT 120°

Figure 10-28. Single Range and Bearing Fix

ranges on the chart. The intersection of the range circles is the fix. If only two targets are used, the range circles cross at two points. The resulting ambiguity is resolved by using dead reckoning information. If three targets are used, there is no ambiguity.

The following procedure is used to obtain a multiple range fix:

1. Identify three targets approximately 120° apart.
2. Note the range to each target being used and the time that this observation is made.
3. Set a draftsman's compass to one of the ranges observed.
4. Place the point of the compass on the chart symbol corresponding to the return and draw an arc on the chart.
5. Repeat this for each range observed. The intersection of the arcs (see figure 10-30) is the fix. The time of the fix is the time noted in step two.

RADAR COMPUTERS

Because of the increasing complexities of navigation and bombing problems in modern high speed aircraft, various computer systems have been devised to assist the navigator in the completion of his mission.

Radar computer systems provide such capabili-

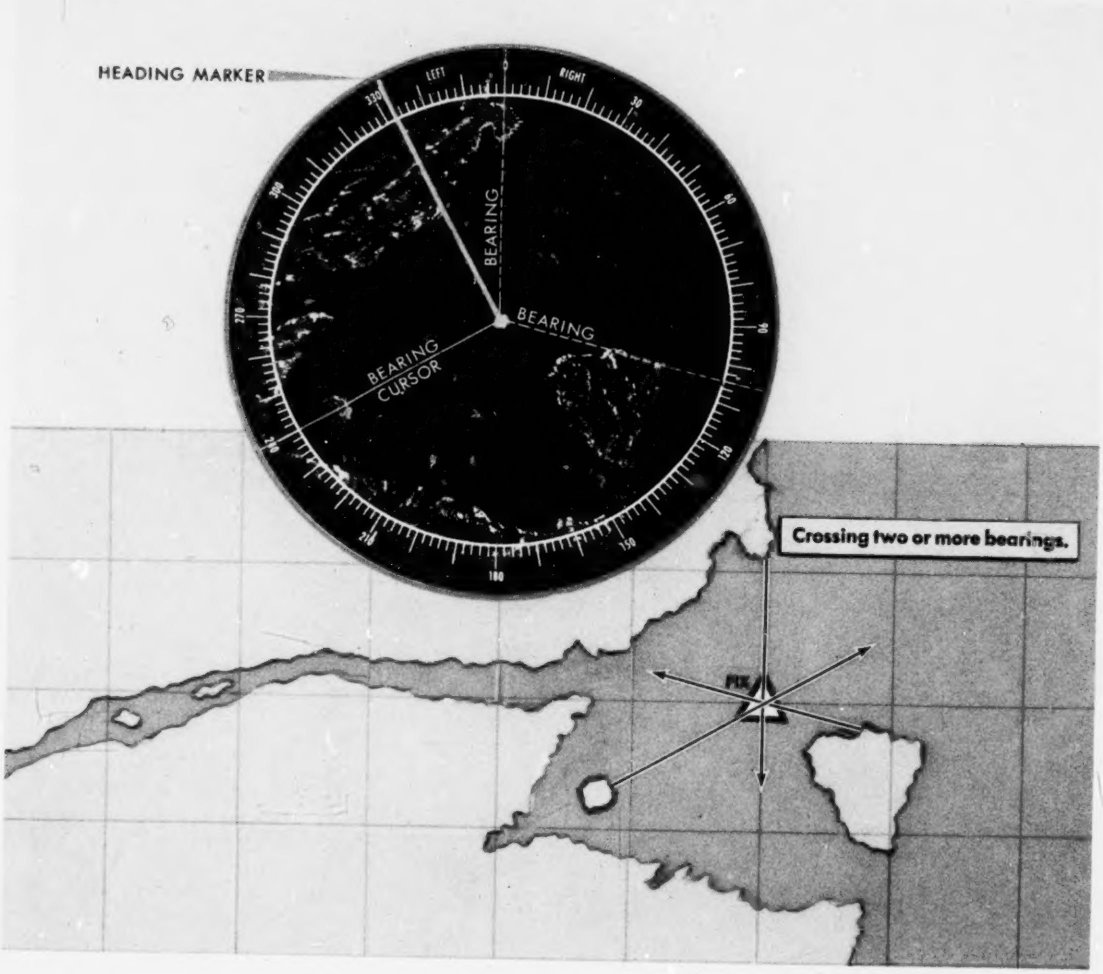


Figure 10-29. Multiple Bearing Fix

ties as precision position determination, wind runs, and bomb runs. These computers range from the relatively simple to the enormously complex. Only the more basic types are discussed here and only that information relative to navigation is included.

To attain precision, the navigator must observe a particular area or point on the scan presentation. This capability is provided by the use of sector scan. As illustrated in figure 10-31, sector scan paints only a portion of the usual full scan presentation. Rather than scanning 360° degrees, the antenna scans only a short arc. It scans in one direction, then reverses itself to scan the same area again. Since the position of the sweep is controlled by the antenna, the sweep paints the area scanned with a clockwise and counterclockwise motion. The resulting presentation is a pie-shaped wedge of radar returns. The vertex of the sector—which may be in the center, on the edge of the radarscope, or beyond the edge of the radar scope—represents the aircraft position. If the heading marker is not in the sectored area, it will not show on the radarscope; however, the fixed range marks will be present.

Other features which may be used with sector scan include the displaced center and the option of having fixed range marks and heading markers

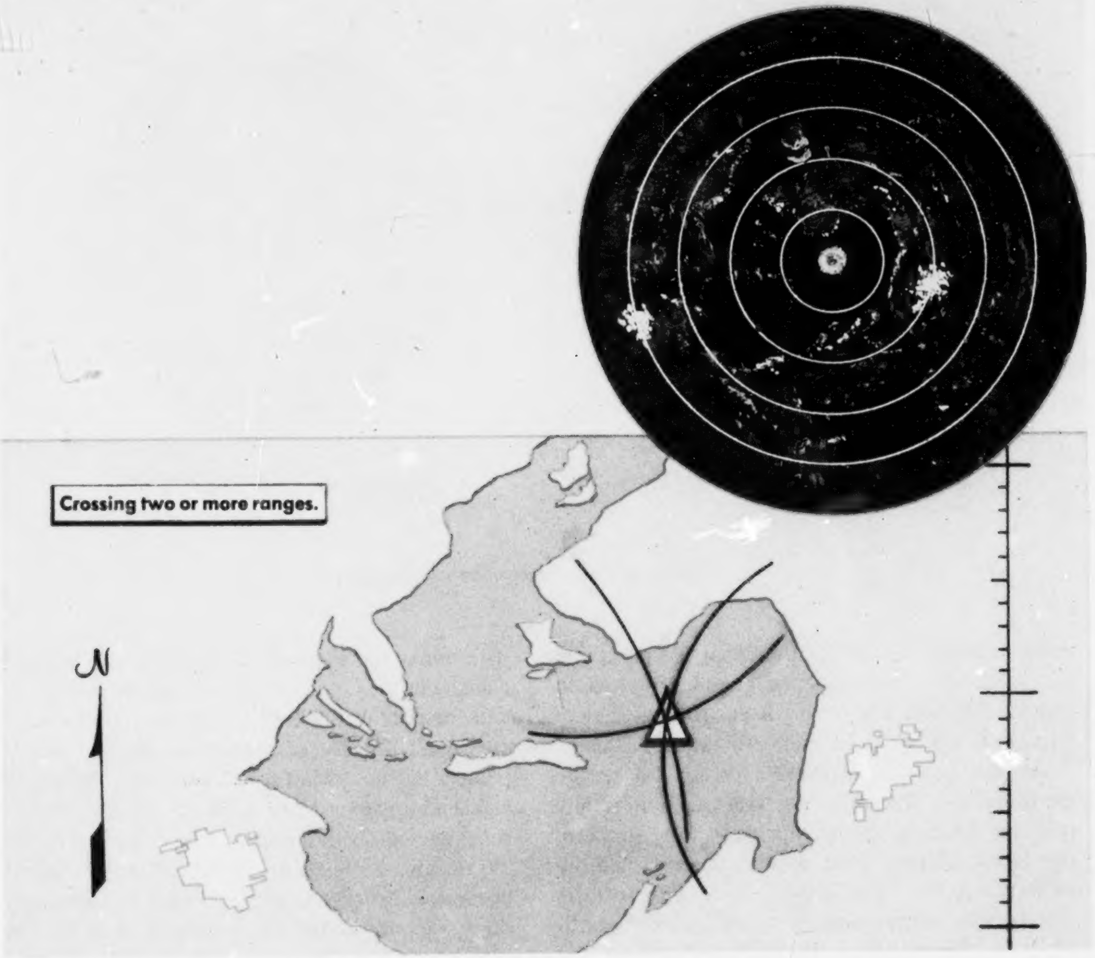


Figure 10-30. Multiple Range Fix

or having crosshairs (one variable range marker and an azimuth marker) in which case the heading marker does not appear.

Crosshairs, when used, are placed on the target with a tracking control in such a manner that the variable range marker and the azimuth marker intersect on the desired point as shown in figure 10-32.

Determining Position

Regardless of the type, all computers require certain information that must be fed into the system either manually or electronically. In turn, the computer will furnish the navigator with the position of the aircraft at any time. If a wind run has been accomplished, this position will be an accurate DR position; if no wind is set into the system, the position will be an air position.

The computer system accomplishes this in the following manner. First, the navigator sets in a departure point by taking a fix on a known object, or by zeroing his fix dials over a known point. From this point on, the system computes the departure from that point. Normally, the navigator will accomplish a "wind run" at the same time that he is taking a fix. This serves to set into the system the latest known wind, and the computer will continue to use this wind until another is set in. The navigator may also set in any known wind, if a "wind run" is not feasible at departure. Since the

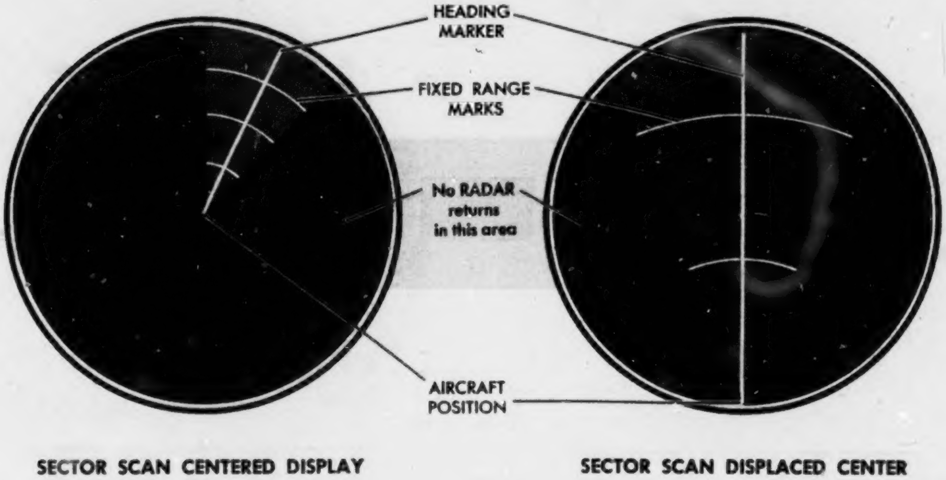

HEADING MARKER
FIXED RANGE MARKS
No RADAR returns in this area
AIRCRAFT POSITION
SECTOR SCAN CENTERED DISPLAY
SECTOR SCAN DISPLACED CENTER

Figure 10-31. Sector Scan Displays

navigator manually sets in the departure point and the wind, some system must be incorporated to provide TH and TAS. This is accomplished electrically by the compass and pitot-static systems.

As the aircraft progresses along track, the navigator can determine the DR position at any time by referring to the "fix dials." In addition, the latest known wind may be ascertained by reference to the "wind dials." Both of these dials will furnish information in "rectangular" coordinates or forces. The fix dials will reflect the distance traveled from departure, in components north, south, east or west. Thus, if after one hour, the position shown on the dials is 150 miles north and 120 miles east, then the position in "polar" coordinates becomes 190 miles from the departure point on a true bearing of 040. By reference to the departure point, a DR position in latitude and longitude can be quickly determined.

Wind Runs

As mentioned earlier, there are radar computers that greatly aid the navigator by furnishing an instantaneous DR position at any time. However, for this DR position to be accurate, frequent wind runs must be made so that an accurate wind is integrated into the system.

With any computer, the wind run is a simple time and distance problem. In the more basic systems the operator notes a particular return, determines the altitude of the return (commonly called a target), and sets the altitude of the aircraft with respect to the target into the set. Next, the crosshairs are placed on the target and the set placed in the "wind run" position. When the crosshairs appear to drift off the target, they are repositioned on the target. This is known as synchronization. When the crosshairs and target are accurately synchronized; i.e., when the crosshairs do not appear to drift off the target, then the wind run is complete and the "wind run" switch is turned off.

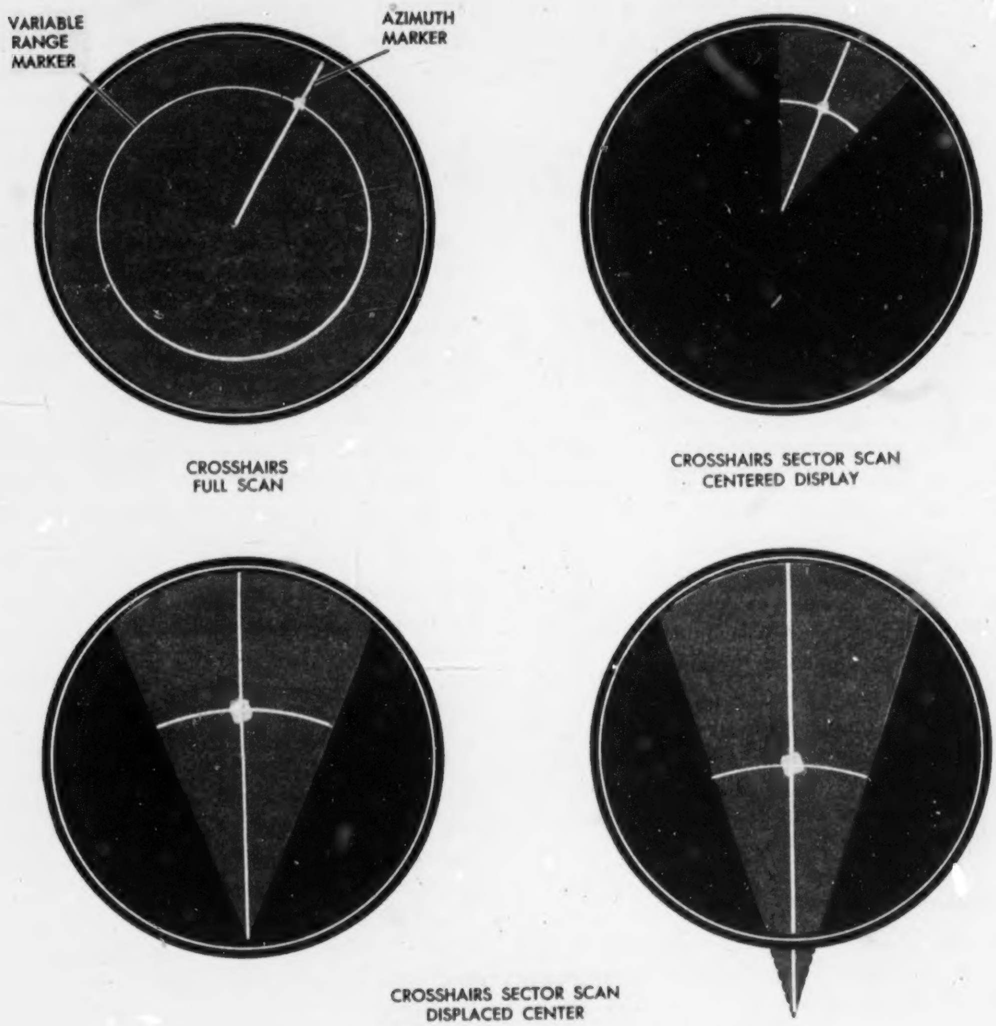
At that time, the rectangular coordinates of the wind may be read on the wind run dials. As with the position dials mentioned earlier, these dials read the forces of the wind in components of north, south, east or west. Thus, if the dials read north 30 and east 15, the resultant wind would be from 026 degrees at 34 knots.

Such a wind run is an accurate spot wind and is automatically fed into the computer system. It remains in the system until another wind run is made or a manual setting of the wind is accomplished.

OTHER RADAR USES

Airborne Radar Approach

The *airborne radar approach* (*ARA*) may be described as GCA in reverse. It is used only as an *emergency procedure* in marginal weather con-



CROSSHAIRS FULL SCAN

CROSSHAIRS SECTOR SCAN CENTERED DISPLAY

CROSSHAIRS SECTOR SCAN DISPLACED CENTER

Figure 10-32. Sector Scans Using Crosshairs

ditions if air-to-ground communication is impossible and no radio navigation aids are available. However, it should be practiced often against the time when it may be the only method of effecting a safe landing. Even when the letdown and approach are directed by ground radar, such direction should be monitored by the navigator on the *airborne* radar.

The ARA involves the use of the airborne radar set to guide the pilot to a point on the final approach where he can either complete the landing visually or decide that the landing cannot be safely completed. This point will be defined by the "minimums" for PPI approaches at the base at which the ARA is made.

There are two main phases in the airborne radar approach—the letdown and the approach itself. The letdown is normally accomplished from a nearby VOR or TACAN station in accordance with published procedures. If these are not available, the letdown is made from a point over the runway using a standard procedure for the type of aircraft flown.

After completion of the letdown, the approach itself is begun. Again, the procedures used vary with the capabilities of the radar used. In general, on radar sets equipped with computers, the crosshairs are used to monitor the distance and direction to the end of the runway; on the other sets, the fixed range markers are used. The specific steps for each type of radar are included in the appropriate aircraft flight handbook.

Station Keeping

Station keeping is a technique wherein radar is used to maintain a fixed position relative to one or more aircraft in flight. With the advent of nuclear weapons, the number of aircraft required to bomb a given area effectively has greatly decreased. Hence, the "tight" bomber formations of World War II are no longer used. Today's bomber formations may require separations on the order of a mile or more.

At distances such as this, radar provides a means of station keeping more accurately. In addition, it is superior to the visual method of formation flying since it is an all weather method.

Positions within the formation are maintained with fixed or variable range markers or with the crosshairs. With radar sets having a highly directional "pencil type" beam, returns appear on any portion of the scope. On other sets, the various aircraft in the formation appear in the altitude hole.

Navigation Through Weather

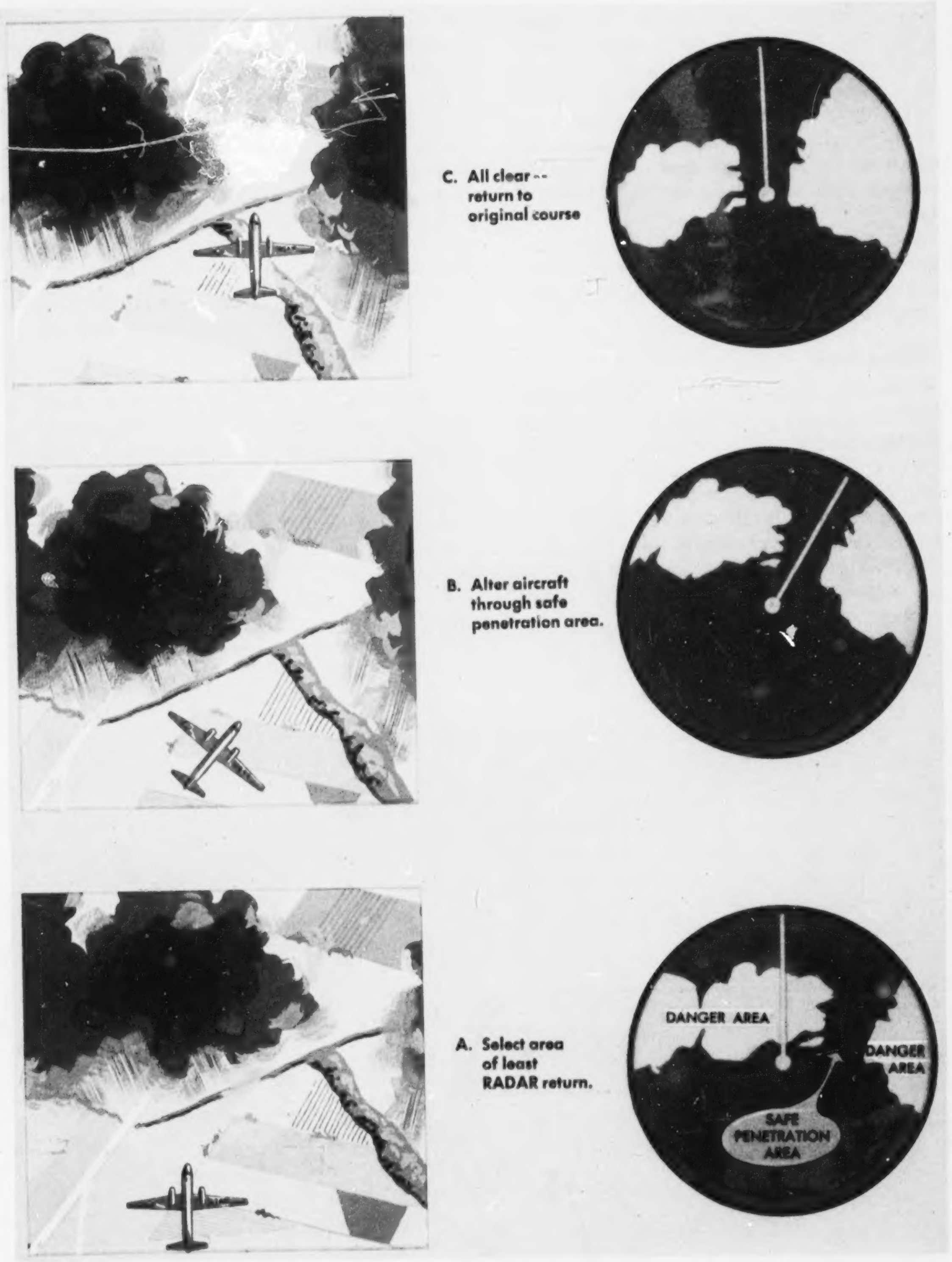
The use of radar for weather avoidance has become increasingly important in recent years from the standpoint of both safety and operational flexibility. The severe turbulence, hail, and icing associated with thunderstorms constitute severe hazards to flight. It is mandatory that these thunderstorms be avoided whenever possible. Airborne weather radar, if operated and interpreted properly, can be an invaluable aid in avoiding thunderstorm areas.

Several factors affect the radar returns from thunderstorms, and the operator must be aware of these and the limitations they impose on the weather radar if he is to make optimum use of this tool. Some of these factors are non-meteorological and depend on the characteristics of the radar set and the way it is operated. The same weather "target" can vary considerably in its radarscope appearance as the operator changes the operating characteristics of the set. The operator must insure that he is using the set as designed for weather avoidance. Primary meteorological factors which affect the radar return are the size, shape, number, and phase of the water droplets in the weather "target" and atmospheric absorption characteristics between the radar antenna and the "target." The most important factors are the number and size of the water droplets.

The operator must realize that the predominant weather-induced returns on most radarscopes are caused by precipitation-size water droplets, not by entire clouds. Intense returns indicate the presence of very large droplets. These large droplets are generally associated with the most hazardous phenomena, since strong vertical currents are necessary to maintain these droplets in the cloud. It is possible however to encounter these phenomena in an echo-free area or even in an adjacent cloud-free area, so avoiding areas giving intense returns will not necessarily guarantee safe flight in the vicinity of thunderstorms. Various researchers have empirically determined what they consider to be safe distances for avoiding these intense returns to avoid hazards. These distances vary with altitude and echo characteristics. Although the avoidance procedures recommended by these researchers vary and change somewhat as research continues, they are similar and rarely recommend passage closer to intense echoes than 10 miles at low altitudes. Avoidance by even greater distances is recommended at higher altitudes.

Weather avoidance with radar is mainly of two types: (1) avoidance of isolated thunderstorms and (2) penetration of a line of thunderstorms. The process of avoiding an isolated return is one of first identifying the return and then circumnavigating it at a safe distance. Penetration of a line of thunderstorms presents a somewhat different problem. Since the line may extend for hundreds of miles, circumnavigation is not often practical nor even possible. If the flight must continue and the line penetrated, the main objective is to avoid the more dangerous areas in the line.

An example of frontal penetration using radar is shown in figure 10-33. Upon approaching the line, the navigator determines an area which has weak or no returns and which is large enough to allow avoidance of all intense returns by the recommended distances throughout penetration. He selects this as the penetration point. The pilot directs the aircraft to that point and makes the penetration at right angles to the line so as to



DANGER AREA
DANGER AREA
SAFE PENETRATION AREA

C. All clear -- return to original course

B. Alter aircraft through safe penetration area.

A. Select area of least RADAR return.

Figure 10-33. Penetration of Thunderstorm Area

remain in the bad weather area for the shortest possible time. *Great care must be taken to avoid the dangerous echoes by the recommended distances.* It should be emphasized that penetration of a line of severe thunderstorms is always a potentially dangerous procedure. It should be attempted only when continuation of the flight is mandatory and the line cannot be circumnavigated.

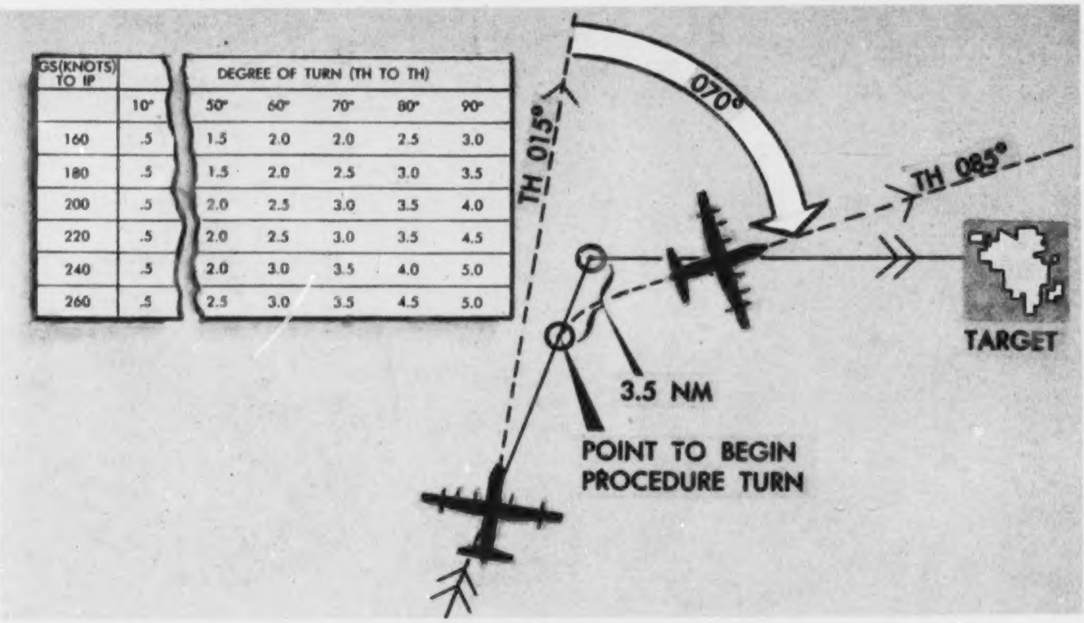
Some airborne radar sets have special features which are extremely useful in weather avoidance. The user should refer to the operating instructions of these sets for further information.

Procedure Turns

A procedure turn is one so planned that the aircraft will roll on the proper heading to make good a predetermined track. For example, in bombing, the bomb run to the target must begin from a fixed point, called the IP (initial point). To roll out on the track from the IP to the target, the turn onto the bomb run must begin at some point *prior* to the IP. This situation is shown in figure 10-34. There are several methods of executing the procedure turn.

COMPUTING THE POINT TO START THE TURN. The point at which a procedure turn should begin is computed on the basis of the amount of turn to be made, the turning *rate*, and the groundspeed of the aircraft. The turn angle and the groundspeed must be determined prior to the turn, through normal navigational procedures. The turn rate is governed by local directives, but it is usually a one-quarter or one-half needlewidth turn. A one-quarter needlewidth turn is an 8-minute, 360° turn, and a one-half needlewidth turn is a 4-minute, 360° turn.

To find the turn distance, enter the table in figure 10-34 for the turning rate to be used. At the intersection of the groundspeed column and the degree of turn column, read the ground distance from the IP to the actual turning point. Plot this distance on the chart. In the illustration, the aircraft is approaching the IP on a true heading of 015° at a groundspeed of 250 knots. The true heading to the target is 085°. Enter the table with 250 knots and 70° (085° — 015°), the difference between the new heading and the old one. The distance from the IP to start the turn is 3.5 nautical miles. The problem now becomes one of determining when the aircraft is at the turning point. This is found in several ways.



GS(KNOTS) TO IP		DEGREE OF TURN (TH TO TH)				
	10°	50°	60°	70°	80°	90°
160	.5	1.5	2.0	2.0	2.5	3.0
180	.5	1.5	2.0	2.5	3.0	3.5
200	.5	2.0	2.5	3.0	3.5	4.0
220	.5	2.0	2.5	3.0	3.5	4.5
240	.5	2.0	3.0	3.5	4.0	5.0
260	.5	2.5	3.0	3.5	4.5	5.0

Figure 10-34. Executing a Procedure Turn

Fixed Range Marker Method. The slant range corresponding to the ground range distance can be computed (refer back to Radar Fixing). When the IP appears at the proper slant range on the scope as indicated by the fixed range markers, execute the turn.

Variable Range Marker Method. When using a radar set on which there is a variable range marker, execute the turn when the IP intersects the VRM.

Bearing Method. If the bearing from the turning point to some easily identifiable ground point is measured, make the turn when the bearing of the aircraft to this point reaches the measured bearing. For greatest accuracy, the line of bearing from the turning point to the reference point should intersect the track at approximately a right angle.

OFF COURSE METHOD. If the aircraft is not on the desired track to the IP, each of the three methods described above will be inaccurate. For example, if the aircraft is several miles to the left of track and the radar operator waits until the IP is 3.5 nautical miles from the aircraft, the aircraft will roll out on a track above that desired. However, if a line is drawn *on the scope* through the IP and in the direction of the new track, make the turn when the *line*—not the IP—is 3.5 nautical miles from the aircraft.

IMPROVEMENTS TO BASIC RADAR

Improvements in navigation equipment are continually being made. This section deals with three improvements to the basic radar set.

Sensitivity Time Constant (STC)

Most radar sets produce a "hot spot" in the center of the radarscope because the high gain setting required to amplify the weak echoes of distant targets over-amplifies the strong echoes of nearby targets. If the receiver gain setting is reduced sufficiently to eliminate the "hot spot," distance returns are weakened or eliminated entirely. The difficulty is most pronounced when radar is used during low-level navigation; to make best use of the radar, the navigator is forced to adjust the receiver gain setting constantly.

STC solves the problem by increasing the gain as the electron beam is deflected from the center to the edge of the radarscope, automatically providing an optimum gain setting for each range displayed. In this manner, the "hot spot" is removed while distant targets are amplified sufficiently.

STC controls vary from one model radar set to another. Refer to the appropriate technical order for operating instructions.

Terrain Avoidance Radar

With the increased emphasis on low-level flights, better equipment was needed for flying safety. Terrain avoidance radar (TAR) gives the aircrew all-weather, low-level capability. As mentioned earlier, interpreting mountain shadows on a normal radarscope can be confusing. There is no time for indecision at low levels and at high speeds. TAR increases safety and eliminates confusion by displaying only those vertical obstructions which project above a selected clearance plane.

The two basic types of presentation used with terrain avoidance radar are illustrated in figure 10-35.

PLAN DISPLAY. The plan display is a sector scan presentation that indicates the range and direction of obstructions projecting above a selected clearance plane. The clearance plane can be manually set at any level from 3000 feet below the aircraft up to the level of the aircraft. In figure 10-35, assume that the clearance plane, represented by the shaded area, is set 1000 feet below the aircraft. Only those peaks projecting above the clearance plane are displayed; all other returns are inconsequential and are eliminated. The sector scan presentation limits the returns to those ahead of the aircraft. The ground track of the aircraft is represented by the vertical line and ranges are determined by range marks.

[illegible]LE DISPLAY. The profile display, normally rec[illegible]d only by the pilot, provides an outline of the terrain 1500 feet above and below the clearance plane. Elevations of returns are represented vertically; azimuth is represented horizontally. This display gives the operator a look "up the valley." The returns which are seen represent the highest terrain within the selected range. The position of the aircraft is represented by an engraved aircraft symbol on the indicator overlay. Figure 10-35 shows both a 3-mile and a 6-mile presentation.

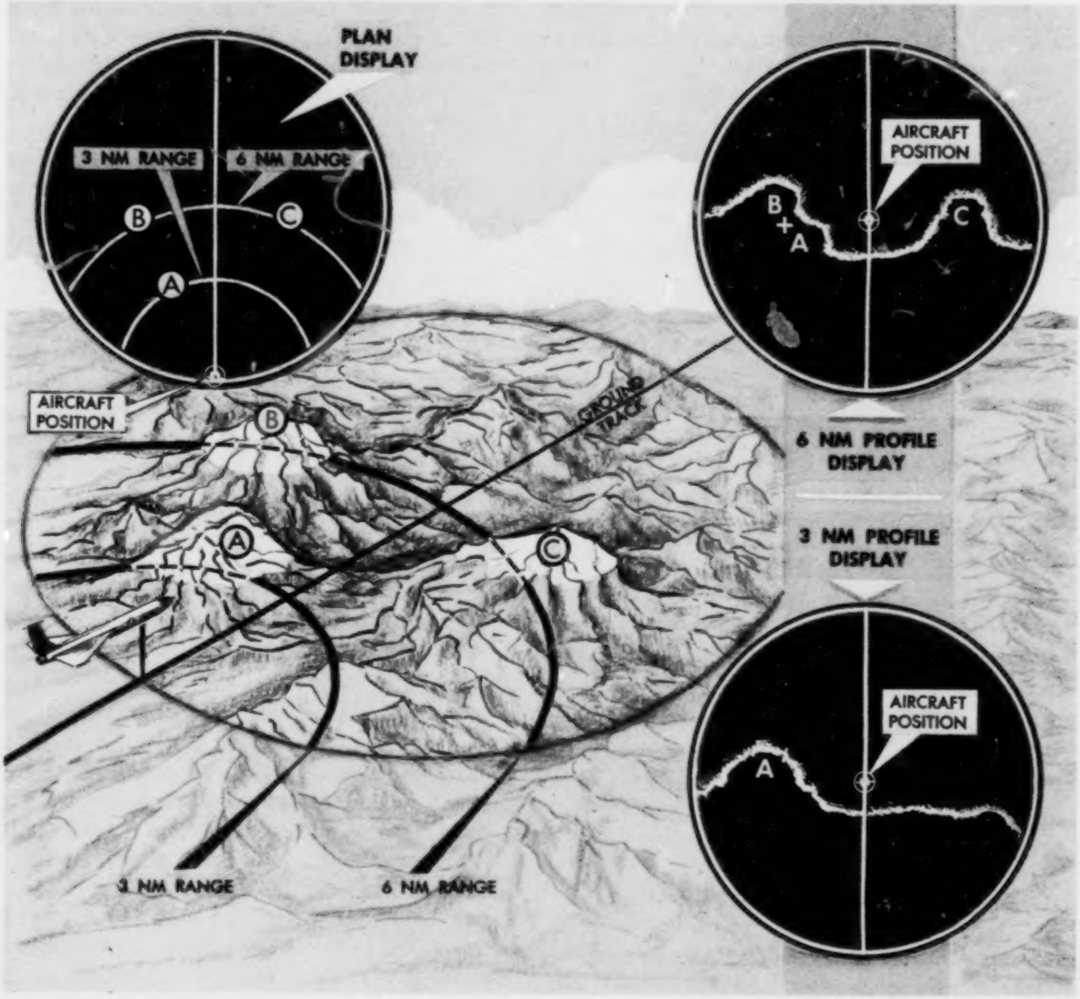

PLAN DISPLAY
3 NM RANGE
6 NM RANGE
B
C
A
AIRCRAFT POSITION
GROUND TRACK
B
A
C
AIRCRAFT POSITION
B
+
A
C
6 NM PROFILE DISPLAY
3 NM PROFILE DISPLAY
AIRCRAFT POSITION
A
3 NM RANGE
6 NM RANGE

Figure 10-35. Terrain Avoidance Radar Presentations

CHAPTER 11

Celestial Concepts

This chapter deals with a general discussion of celestial concepts and definitions. The more this material is understood, the easier it will be to grasp the mechanics of celestial navigation.

When the ground is not visible and a position cannot be established with other methods, celestial observations offer the only available aid to dead reckoning. On long overwater flights, flights over uncharted areas, or deep penetration into enemy territory, celestial navigation becomes indispensable. Since most aircraft fly at high altitudes above normal cloud coverage, celestial navigation is an aid to dead reckoning which is available most of the time. It has worldwide coverage, and hence is exceptionally useful in polar regions. Furthermore, this type of navigation is not subject to enemy detection or jamming — an intangible advantage whose value can never be over estimated.

Each celestial observation yields one line of position. In the daytime, when the sun may be the only visible celestial body, it may become necessary to use successive LOPs singly as course lines or speed lines. At night, however, when numerous bodies are visible, LOPs obtained from the observation of two or more bodies may be crossed to determine a fix.

It is impossible to state, in so many miles, the accuracy expected from a celestial fix. Celestial accuracy depends on many things, such as the navigator's knowledge and skill, the type and accuracy of the equipment and instruments, the speed of the aircraft, and the prevailing weather conditions. With the ever-increasing speeds and ranges of aircraft, celestial navigation not only becomes more necessary, but also more demanding of the navigator's ability. Further, it becomes more important that the fix be plotted and used as quickly as possible. More accurate instruments are needed as well as improved techniques to minimize errors and reduce the time consumed in celestial navigation.

The necessary equipment presently being used consists of:

- A sextant for observing the celestial body.
- A watch from which the time of observation can be determined to the nearest second.
- An *Air Almanac* for locating the position of the celestial body observed.
- Celestial tables for computing the line of position.

The navigator does not have to be an astronomer or mathematician to establish a celestial line of position. The ability to use a sextant is a matter of practice, and specially designed celestial tables have reduced the necessary computations to simple arithmetic.

With regard to celestial navigation, such questions may arise as: What information do celestial observations provide? How can this information be used to determine an LOP? The answers to these questions are based on some fundamental ideas which are presented in this chapter.

BASIC CELESTIAL CONCEPTS

Certain basic concepts underlie the celestial ideas to be discussed here. The first of these is the *sphere*. A sphere is a ball-shaped object, so formed that every point on its surface is equidistant from its center. The earth is not a true sphere; however, for navigational purposes, it is considered perfect and is called the *terrestrial sphere*.

Any circle on a sphere whose plane passes through the center of that sphere is called a *great* *circle*. The equator and all meridians are great circles on the terrestrial spheres. Any circle on a sphere whose plane does not pass through the center of the sphere is called a *small circle*. Parallels of latitude (excepting the equator) are small circles on the terrestrial sphere since their planes do not coincide with the center of the earth.

On a clear night a vast array of stars and perhaps several planets and the moon are visible. The stars move across the sky from east to west, while maintaining fixed positions relative to one another. Figure 11-1 shows how the Big Dipper has moved in the sky, but the same pattern still exists. The planets and the moon, on the other hand, appear to move among the stars. The planets are scattered through space at different distances from the earth and follow complicated motions of their own.

In celestial navigation, it is assumed that all the heavenly bodies are on the inner surface of an infinitely large sphere whose center is the center of the earth. This imaginary sphere is known as the *celestial sphere*. This sphere and the bodies upon it are assumed to rotate westward about an axis which is the extension of the earth's axis, while a few of the bodies, such as the moon and planets, move over the surface of the sphere.

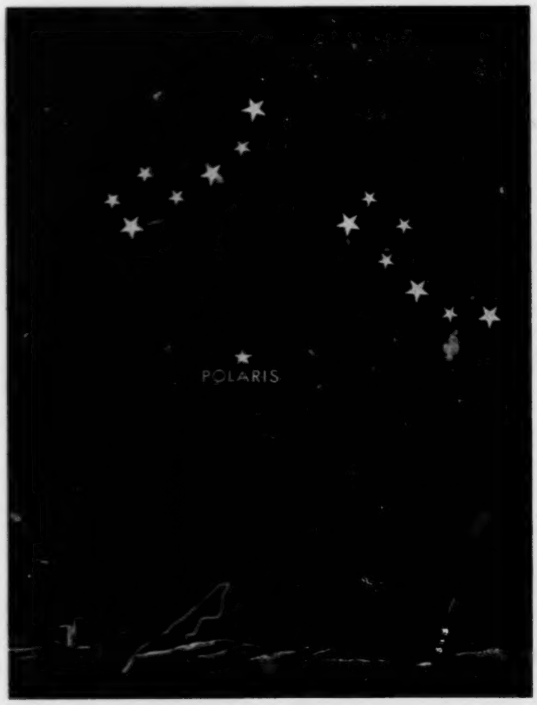


Figure 11-1. Stars Maintain Fixed Positions Relative to One Another

Since the radius of the celestial sphere is infinite, you could be a considerable distance from the center of the sphere without being perceptibly closer to one side than to the other. Therefore, any point on the earth may be assumed as being the center of the celestial sphere.

Although the celestial sphere is purely imaginary, the assumption of its existence is justified because the results obtained under this assumption are accurate enough for the purposes of navigation. The celestial bodies are so far from the earth that any one of them appears to be projected on the same point on the sphere, regardless of your position on the earth at the moment. The only body that is an exception is the moon, which is so near the earth that it must be treated as a special case.

An important consequence of the great distances of the celestial bodies from the earth is that the light rays received from one body appear parallel at different positions on the earth. The stars are so far away that very precise instruments are required to measure the divergence of their light rays, even for two positions on opposite sides of the earth's orbit. Therefore, for practical purposes, the light from any heavenly body, except the moon, is regarded as striking the earth in parallel rays.

The moon, however, is so close to the earth that individuals at different parts of the earth see the moon along lines of sight which are not parallel. This means that you must apply a special correction to sextant observations of the moon.

Since the earth and the celestial sphere are geometrically similar, every point on the surface of the earth has a corresponding point on the celestial sphere, and every point on the celestial sphere has a corresponding point on the earth. Therefore, any point on the earth may be projected onto the celestial sphere; conversely, any point on the celestial sphere may be projected onto the earth.

A point on the earth is projected onto the celestial sphere by drawing a line from the center of the earth through the point and extending it to infinity to intersect the celestial sphere. This line is perpendicular to the surface of the earth and to the surface of the celestial sphere. Thus, the north and south terrestrial poles may be projected along the earth's axis onto the celestial sphere to form the north and south celestial poles.

The *celestial axis* is an extension of the earth's axis to the celestial sphere and the *Equinoctial* or *Celestial Equator* is an extension of the plane of the earth's equator to the celestial sphere.

A point on the celestial sphere is projected onto the earth by dropping a perpendicular from the point to the surface of the earth; if this line were extended, it would pass through the center of the earth. The point on the earth at which a celestial body is projected is the *subpoint* or geographical position of the body. At the subpoint, the rays of light from the body are perpendicular to the surface of the earth. In figure 11-2, the observer is standing at the subpoint—the body is directly overhead.

Each star appears as a point of light on the celestial sphere. The subpoint of a star is the subpoint of this point of light. On the other hand, the sun, moon, and planets appear not as points, but as disks with measurable width. The subpoint of one of these bodies is the subpoint of the center of the disk.

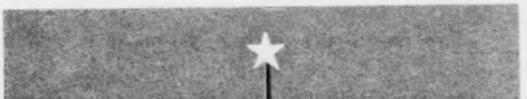


Figure 11-2. Standing at the Subpoint, the Body is Directly Overhead

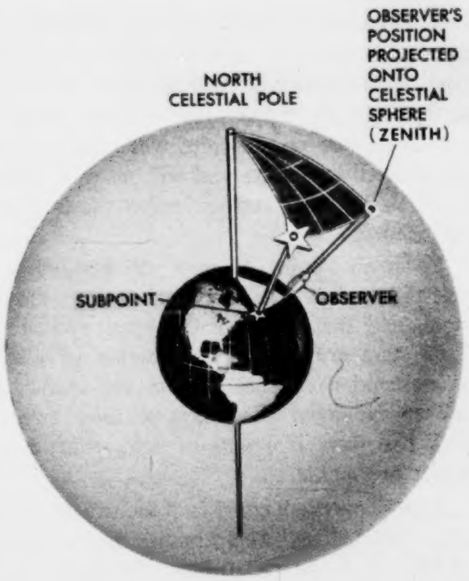

OBSERVER'S POSITION PROJECTED ONTO CELESTIAL SPHERE (ZENITH)
NORTH CELESTIAL POLE
SUBPOINT
OBSERVER

Figure 11-3. Points on Celestial Sphere Have Same Relationship as Their Subpoints on Earth

Notice in figure 11-3 that, because of the geometrical similarity of the earth and the celestial sphere, points on the celestial sphere have the same relationship as their subpoints on the earth. Thus, the angular distance between two points is the same as the angular distance between their subpoints. And the direction from one point to another is the same as the direction from the subpoint of one to the subpoint of the other. Conversely, points on the earth may be projected to the celestial sphere and geometric relationships established. These simple principles of spherical geometry make it possible to establish LOPs from celestial observations.

Since the celestial sphere and the bodies on it apparently rotate westward, the subpoint of each body moves continuously westward across the surface of the earth. For any instant, however, the geographical position of a body can be located by means of tables in the *Air Almanac* which are discussed later.

MOTIONS OF CELESTIAL BODIES

The true relationship of the celestial bodies does not have to be understood as long as a few basic facts concerning their apparent relationships to the earth are known. However, an understanding of the true relationships will increase interest in celestial navigation and will make it easier to learn, understand, and remember the facts which are needed.

From the point of view of navigation, the celestial bodies fall into two classes: the fixed stars, and the bodies of the solar system. The fixed stars are incandescent bodies of vast size at tremendous distances from the earth. They are so far away that, despite their size, they look like mere pinpoints of light which seem to waver or twinkle.

The solar system consists of the sun, the planets, and the satellites. These bodies are important to us because of their nearness to the earth, which is itself a planet of the solar system. The planets, including the earth, are bodies which move about the sun. They are cold and shine by the reflected light of the sun.

Four planets are used in navigation: Venus, Mars, Jupiter, and Saturn. They look like very bright stars and usually shine with an unwavering light. Satellites are smaller bodies which move about the planets. The only natural satellite of importance to us is the moon, which moves about the earth. It, too, shines by the reflected light of the sun.

Earth's Principal Motions

The two principal motions of the earth which cause apparent motions of the celestial bodies are rotation and revolution. *Rotation* is the turning of the earth about its own axis. *Revolution* is the motion of the earth along an elliptical path about the sun. There are other motions of the earth which are discussed later.

ROTATION: The earth rotates on its own axis once every 24 hours. It turns from west to east, or counterclockwise, as seen from above the North Pole. The stars appear to be fixed in space, but this motion of the earth causes them to appear to rotate from east to west. On the earth it seems as though the navigator is standing still, while the celestial bodies appear to move from east to west. Hence, he sees the celestial bodies rise in the east and set in the west. Figure 11-4 shows the subpoints of stars as moving westward over the earth's surface.

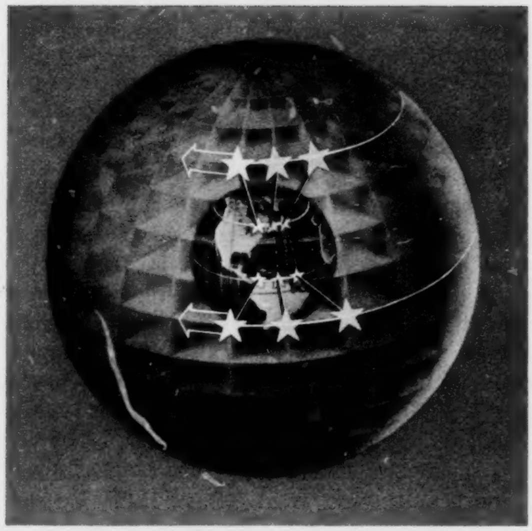


Figure 11-4. Subpoints of Stars Move Westward Along Parallels of Latitude

The daily path of the subpoint is called a *diurnal circle.* Notice that the diurnal circle of a star is a parallel of latitude corresponding to the declination of that particular star (refer to figure 11-5).

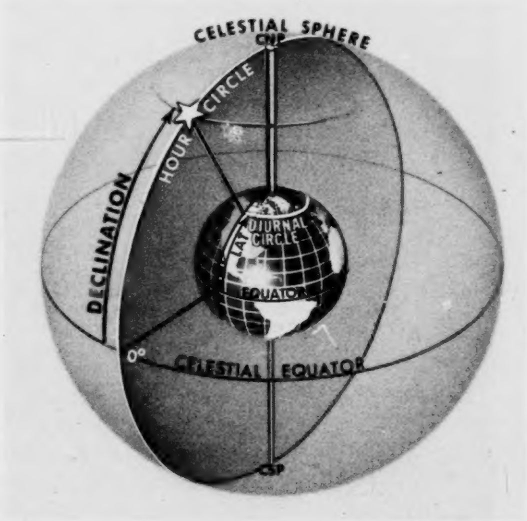


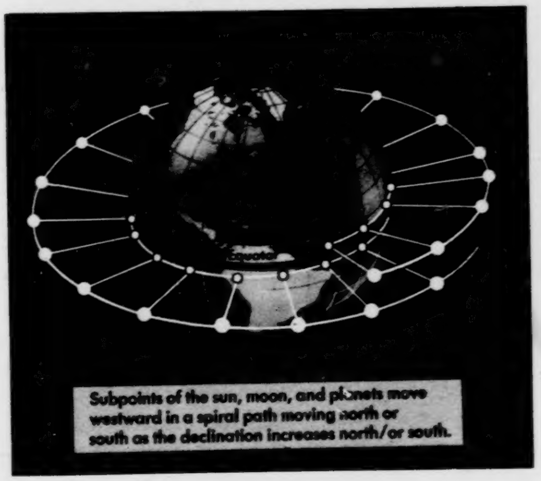
Figure 11-5. Declination of a Star Corresponds to a Parallel of Latitude

The declinations of those bodies within the solar system (sun, moon, and planets) change constantly. The daily paths of their respective subpoints are not really circles, but rather spirals which move north or south with changes of declination, as shown in figure 11-6.

The paths they seem to trace vary with latitude. Consider here the appearance of the heavens to observers at the equator, at the North Pole, and at a middle latitude.

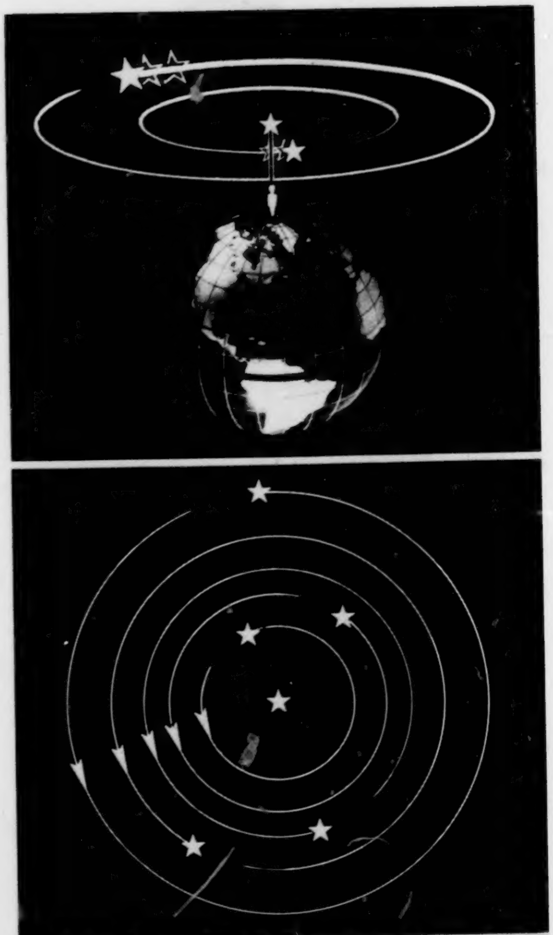
In figure 11-7, the observer is at the North Pole. As the earth rotates on its axis from west to east, the apparent motion of all other bodies is in the opposite direction, always at the same altitude above the horizon, never rising or setting. Thus, the same stars are above the horizon throughout the year.

As the sun, the moon, or the planets become northerly in declination, they become visible to the observer at the North Pole. When the sun is visible, the stars and north declination planets can no longer be seen, but they are still there. The sun changes in altitude throughout a given period of time by the amount of declination change. Since the sun has a northerly declination about one-half of the year, the sun is visible for about six months continuously, after which there is a six-month period of twilight and night. This is true because the celestial horizon and equator are coincident, and any body with a northerly declination is above the horizon. All stars with northerly

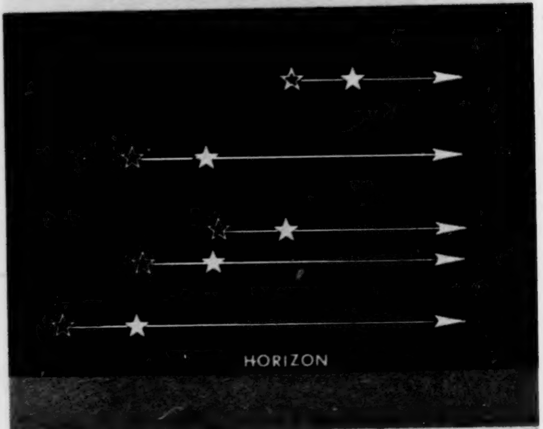


Subpoints of the sun, moon, and planets move westward in a spiral path moving north or south as the declination increases north/or south.

Figure 11-6. Declinations of Sun, Moon, and Planets Change Constantly



Appearance of the heavens and paths of the stars overhead to the observer at the North Pole.



Appearance of the heavens and apparent paths of the stars looking at the horizon for the observer at the North Pole.

Figure 11-7. Observer at the North Pole

declination are visible throughout the long period of night and all are circumpolar; that is they never set, but appear to make a circular path about the north celestial pole.

The greater the northerly declination of a body, the higher it appears in the heavens to an observer at the North Pole. Polaris, the north star, has a very high northerly declination and consequently is practically overhead for the observer at the North Pole.

To the observer at the equator, the north and south celestial poles are on the horizon. Every body is above the horizon for half a day, and below for the other half.

To an observer at an intermediate latitude, the appearance of the motions of the celestial bodies is intermediate between their appearance at the equator and their appearance at the poles. At middle latitudes, the equator is oblique to the horizon. The pole that has the same name as the observer's latitude is called the elevated pole.

Refer to figure 11-8, where the observer is at an intermediate latitude. If the angular distance of the body from the elevated pole is less than the observer's latitude, the body is circumpolar. A body is circumpolar when it seems to revolve around the pole without ever going below the horizon. Although figure 11-8 shows north latitude, the same thing applies for south latitude. To an observer in north latitude, a north circumpolar body never sets. The subpoint of Dubhe, whose declination is 62°00′ N, is 28°00′ from the North Pole. Therefore, Dubhe is circumpolar north of latitude 28°01′ N.

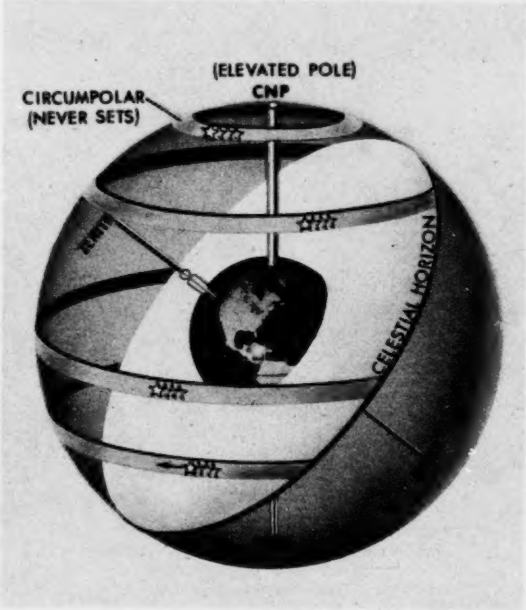


Figure 11-8. Some Bodies are Circumpolar

The greater the observer's latitude, the greater the proportion of the bodies that are circumpolar. At the equator no body appears to be circumpolar. At the pole, all visible stars are circumpolar.

REVOLUTION: Simultaneous with rotation, the earth has another important movement. The earth revolves eastward around the sun, making one complete revolution every year. The path it follows, called its *orbit*, is a nearly circular ellipse, whose average radius is about 93 million miles.

Revolution causes the appearance of the heavens to change through the year. It also contributes to changes in the sun's declination and to changes in the seasons. This motion of the sun is along a great circle path called the *ecliptic*.

Revolution does not appreciably affect the declination of the stars because they are at great distances and the light rays from them are nearly parallel.

In figure 11-9, consider the observer as being on the equator at noontime looking at the sun in each of the four positions of the earth. Notice that this would place the subpoint of the sun in four very different positions on the earth. These are the four points along the ecliptic that are presently discussed in detail.

THE ECLIPTIC. The apparent motion of the sun on the celestial sphere is caused by the revolution of the earth about the sun. As the earth moves in its orbit, the stars overhead at midday shift from day to day just as do the stars overhead at midnight. Thus, from each new daily viewpoint on the earth's orbit, the sun is seen projected against a different point on the invisible background of stars. In the course of a year, as the earth goes around the sun, the sun seems to make a complete circuit of the earth as shown in figure 11-10.

The motion is not along the equator, but along another great circle, called the *ecliptic*, which is inclined to the equator at an angle of about 23°27′. The ecliptic is shown in figure 11-11. This great circle lies in the plane of the earth's orbit around the sun, since it is this actual motion

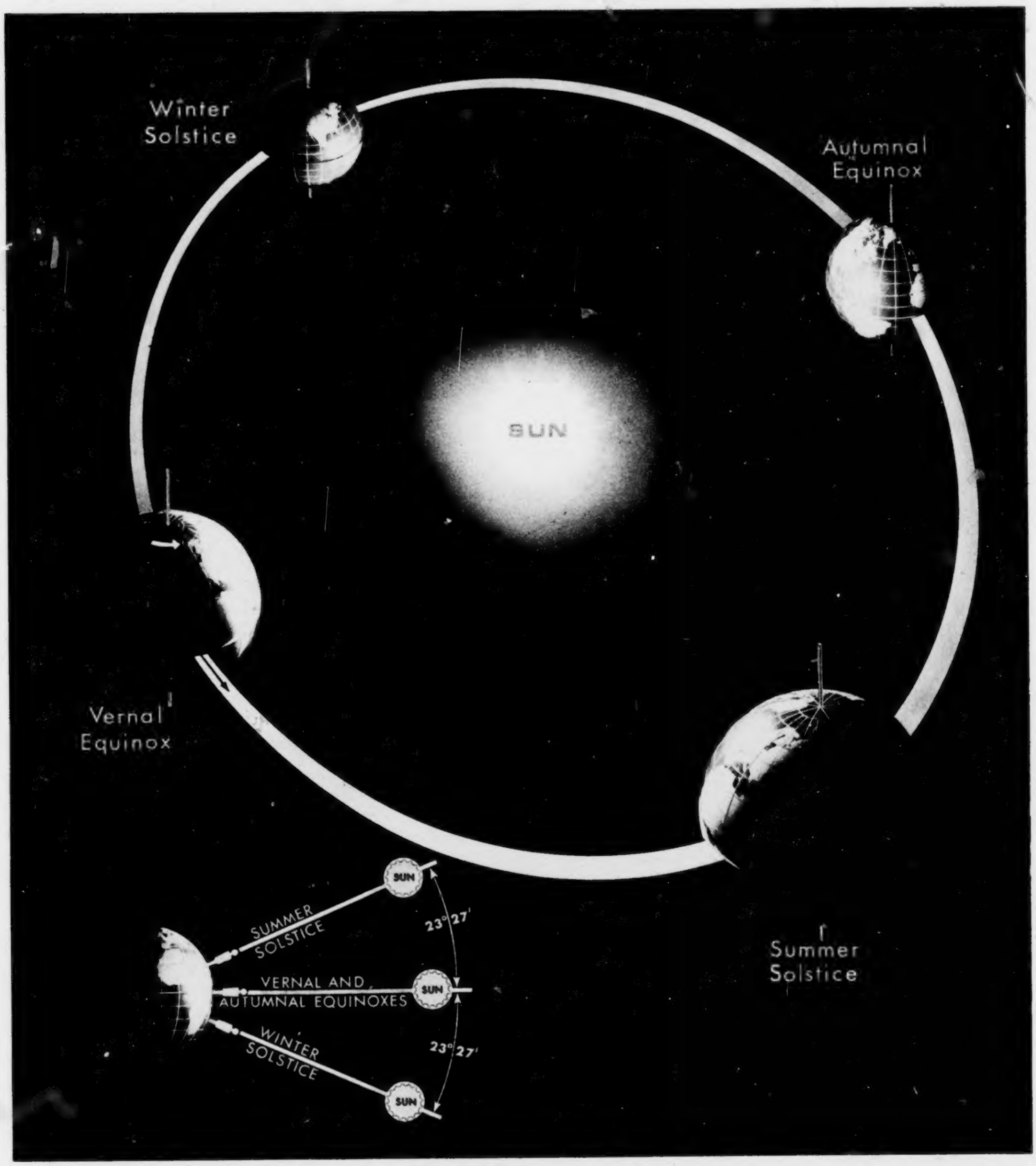

Winter Solstice
Autumnal Equinox
SUN
Vernal Equinox
Summer Solstice
SUN
SUMMER SOLSTICE
23°27'
VERNAL AND AUTUMNAL EQUINOXES
SUN
WINTER SOLSTICE
23°27'
SUN

Figure 11-9. Seasonal Changes of Earth's Position

that causes the apparent motion of the sun. Therefore, the ecliptic may also be defined as the apparent path of the sun among the stars.

Seasonal Appearance of Sky. An observer outside of the polar regions will notice a change throughout the year in the constellations which are visible at a given time of night. Consider the changes which would appear to an observer at the equator.

As the earth revolves in its orbit, it continuously rotates on its axis. Night and day are determined by which side of the earth is turned toward the sun. Although stars are ever present, they are not visible when the sun is above the

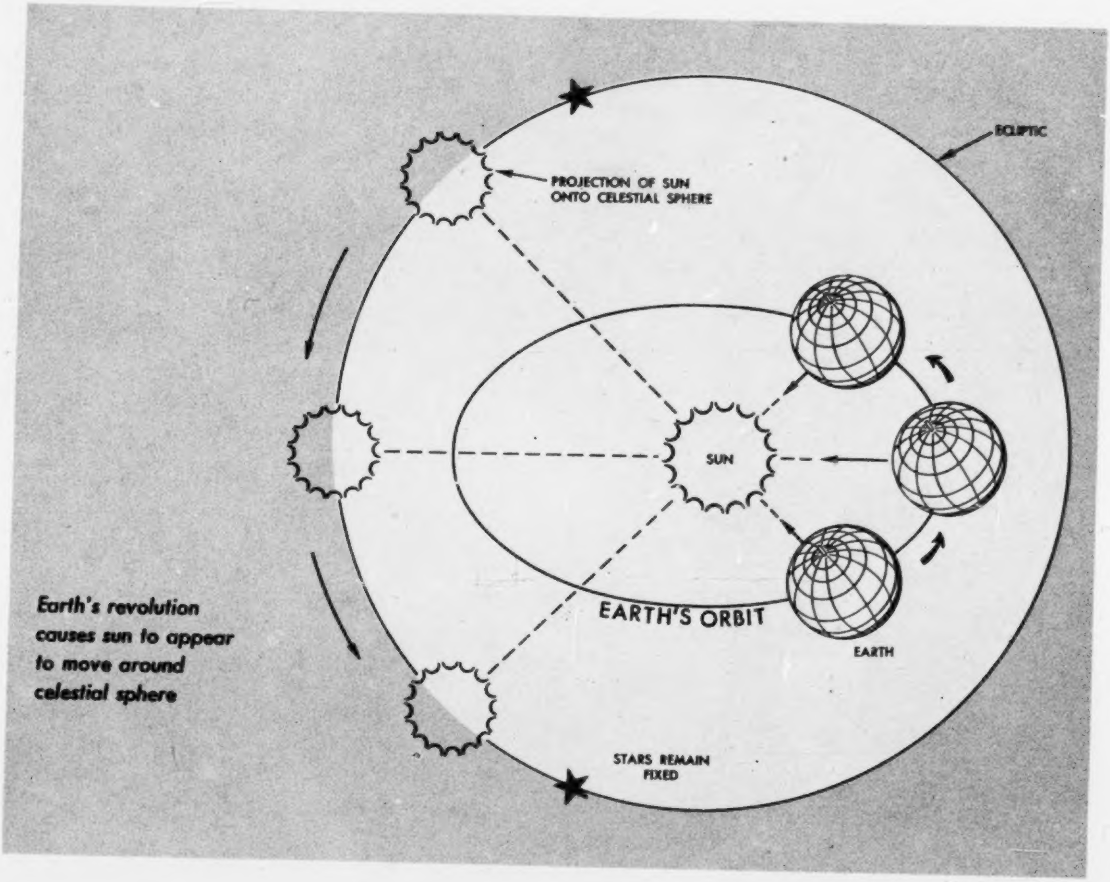

ECLIPTIC
PROJECTION OF SUN ONTO CELESTIAL SPHERE
SUN
EARTH'S ORBIT
EARTH
STARS REMAIN FIXED
Earth's revolution causes sun to appear to move around celestial sphere

Figure 11-10. Apparent Motion of the Sun

horizon. The stars are visible only from the side of the earth away from the sun, where it is night.

The earth makes one complete revolution in its orbit in about 365 days. In other words, every day the earth moves about 1/365th of the way around its orbit, or nearly 1° of the annual 360°. Thus, each night the earth has swung around so that its dark side is turned in a different direction in space by nearly 1°. Consequently, each night the panorama of stars visible, for example at midnight, has shifted to include stars about 1° farther east.

After half a year, when the earth has reached the opposite extreme of its orbit, its dark side is turned in the opposite direction in space and is facing a new field of stars. Hence, an observer at the equator will see an entirely different sky at midnight in June than that which he saw at midnight in December. In fact, the stars he sees at midnight in June are those which were above the horizon at midday in December, but not visible because of the sun.

Seasons. The annual variation of the sun's declination and the consequent change of the seasons are caused by the revolution of the earth together with the obliquity of the ecliptic. If the equinoctial coincided with the ecliptic, the sun would always be overhead at the equator, and its declination would always be zero. However, the earth's axis is inclined to the plane of the earth's orbit at an angle of about 66½°; and the plane of the equator is inclined to it at an angle of about 23½°. Throughout the year the axis points in the same direction. That is, the axis of the earth in one part of the orbit is essentially parallel to the axis of the earth in any other part of the orbit.

In June the North Pole is inclined toward the sun and the South Pole away from the sun, so

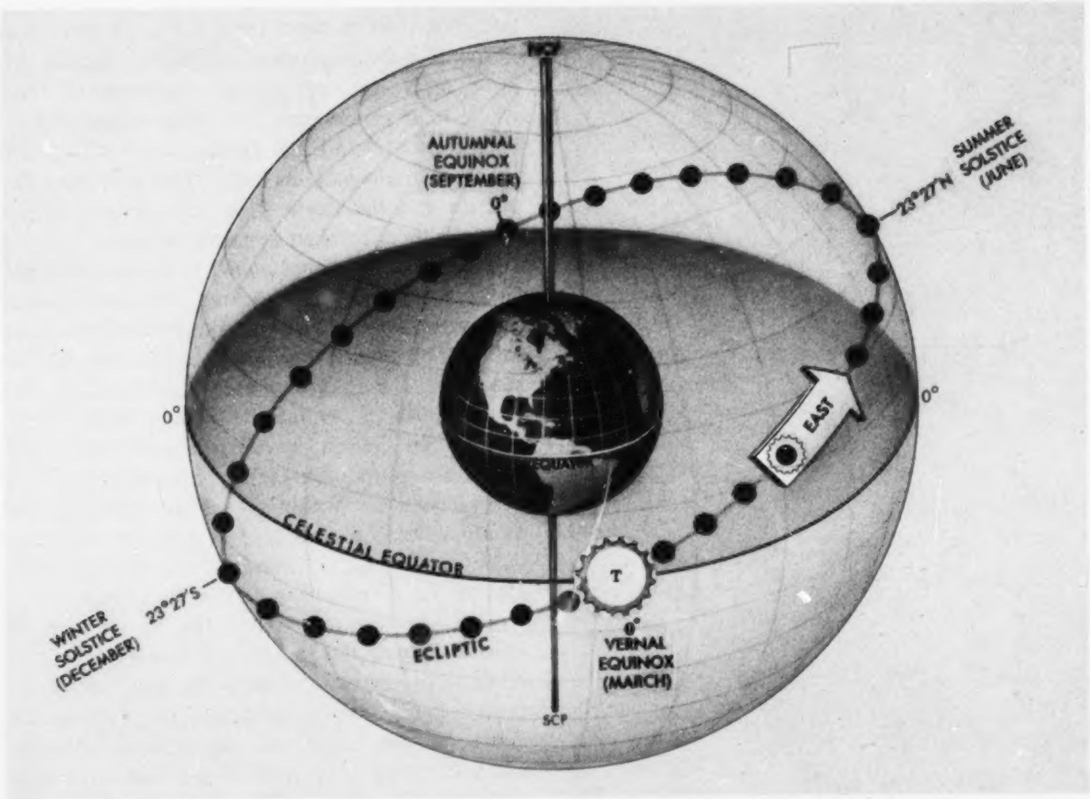


Figure 11-11. Ecliptic with Solstices and Equinoxes

that the sun is at a maximum distance from the plane of the equator. About June 22, at the solstice, the sun has its greatest northern declination. At this time in the Northern Hemisphere the days are longest of any time during the year and the nights are shortest, while in the Southern Hemisphere the nights are longest and days shortest. This is the beginning of summer for the Northern Hemisphere and of winter for the Southern Hemisphere. A half year later the axis is still pointing in the same direction in space; but since the earth is at the opposite extremity of its orbit and hence on the opposite side of the sun, the North Pole is inclined away from the sun and the South Pole toward it. At the other solstice, about December 21, the sun has its greatest southern declination. Then in the Northern Hemisphere days are shortest and nights longest, and winter is beginning.

Halfway between the two solstices, the axis of the earth is inclined neither toward nor away from the sun, and the sun is on the plane of the equator; i.e., the sun's declination is zero. This condition occurs at the equinoxes on March 21 and September 23, which mark the beginning of spring and autumn respectively in the Northern Hemisphere. The first point of Aries, which is used as a reference point for measuring sidereal hour angle, (SHA), is the point where the sun appears to cross the *equinoctial* from south to north. Notice in figure 11-11 that this point, as well as the time of crossing, is called the vernal equinox. The other equinox is called the autumnal equinox.

Motions of Other Bodies

Having considered the real motions of the earth and the resulting apparent motions of the celestial bodies, now consider the real motions of these celestial bodies with respect to one another, and how they further affect these apparent motions. The *fixed stars* are so called because they appear to maintain the same relationship to one another year after year. Actually, these stars are in rapid mo-

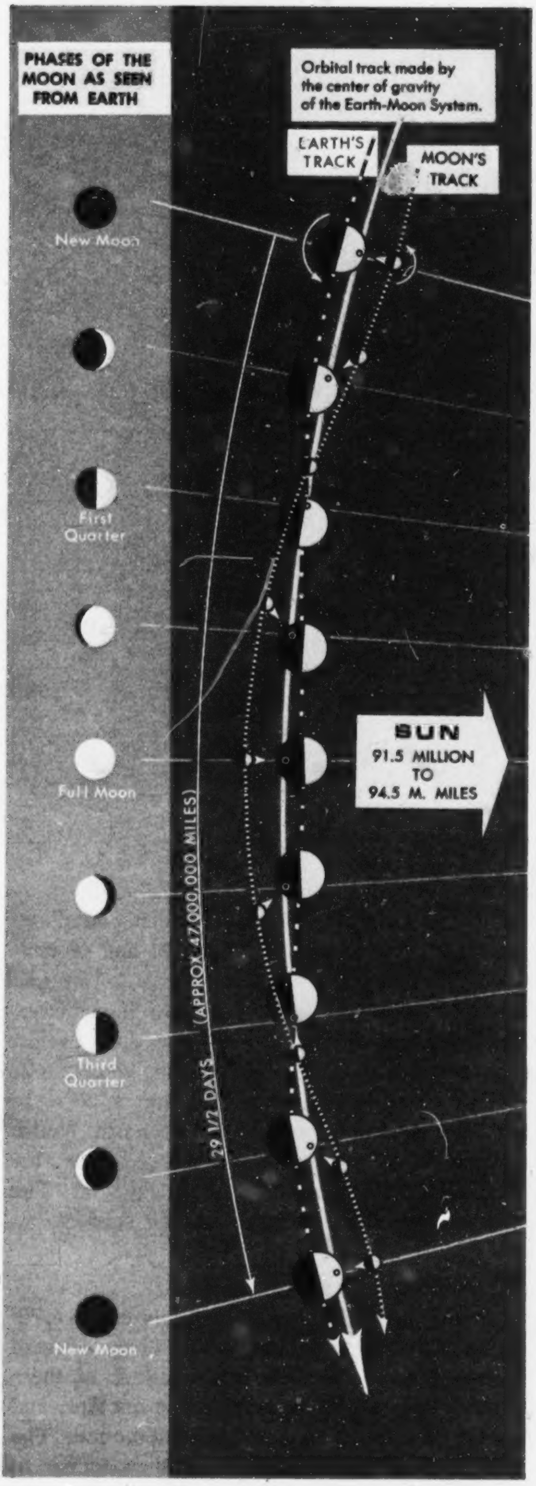

PHASES OF THE MOON AS SEEN FROM EARTH
Orbital track made by the center of gravity of the Earth-Moon System.
EARTH'S TRACK
MOON'S TRACK
New Moon
First Quarter
Full Moon
Third Quarter
New Moon
SUN
91.5 MILLION TO 94.5 M. MILES
29 1/2 DAYS (APPROX 47,000,000 MILES)

Figure 11-12. Motion of the Moon

tion, but their distance from the earth is so immense that their apparent movements can be detected only by very precise measurement. The whole solar system, too, is moving through space, but the sun has no real motion which affects the apparent motions of any body. Therefore, only the planets and the moon have real motions which appreciably affect their apparent motions.

PLANETS. The word *planet* is derived from the Greek word meaning wanderer. The astronomers discovered these bodies wandered among the fixed stars. The planets revolve in orbits around the sun. Venus, in an orbit closer to the sun than that of the earth, is an inferior planet; while Mars, Jupiter, and Saturn, in orbits beyond that of the earth, are superior planets. Since the planes of these orbits are within 3° of the plane of the earth's orbit, the planets always appear to move in the band of the sky known as the *Zodiac,* which extends for 8° on either side of the ecliptic.

For the same reason that the sun appears to move eastward, the planets also usually appear to move slowly eastward among the stars. However, their apparent rate of movement is very irregular and sometimes they even appear to move westward. If the observer watches a planet night after night, he will see that it has about the same position among the stars but from week to week he usually will be able to detect its motion.

MOON. The moon revolves eastward about the earth in a period of about 29½ days, and during this time it appears to make a complete circuit of the earth. Thus, its apparent motion relative to the stars is rapid (amounting to about 13° per day), and is conspicuous to the observer from one night to the next. The plane of the moon's orbit is inclined at about 5° to the plane of the ecliptic. Consequently, the moon's declination may change as much as 57° in one month.

As the moon revolves in its orbit eastward about the earth, it also rotates eastward on its axis. This rotation of the moon takes 29½ days. Figure 11-12 shows why an observer always sees the same side of the moon.

CELESTIAL COORDINATES

To plot a celestial LOP, the subpoint of the observed body must be located for the time of observation. Therefore, the navigator must be able to locate the geographical position of any body for any time.

A body's subpoint can be positioned on the earth by spherical coordinates similar to latitude and longitude. The reference lines used are counterparts of meridians and parallels of latitude. Those celestial reference lines which are counterparts of parallels of latitude are called *declination circles*.

The counterparts of meridians of longitude are called *hour circles*. An hour circle is a great circle passing through the poles and a given celestial body. An hour circle does not correspond to any particular meridian, because of the apparent rotation of the celestial bodies. All hour circles and meridians are divided by the poles. That half of an hour circle or meridian which contains the celestial body or the observer's position is called the *upper branch*. The opposite half is the *lower branch*. The upper branch is frequently used in navigation and references to a celestial meridian or hour circle are understood to mean only its upper branch unless otherwise stated. Figure 11-13 shows the elements of the celestial sphere.

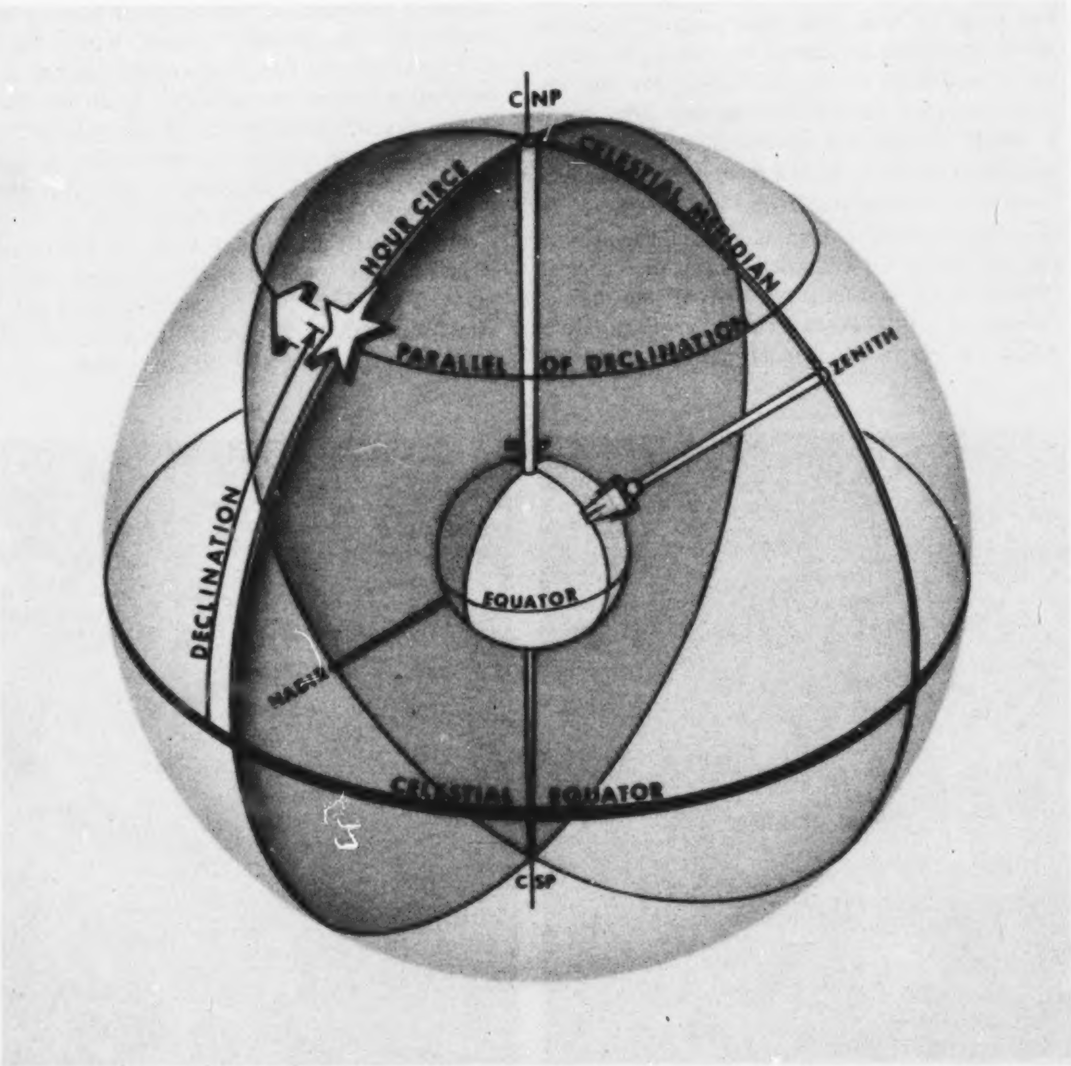


Figure 11-13. Elements of the Celestial Sphere

Declination and Sidereal Hour Angle (SHA)

Position on the earth is stated with relation to the equator and the Greenwich meridian. Likewise, position of the subpoints of celestial bodies are stated with relation to the equator and an arbitrarily selected hour circle.

DECLINATION. The declination of a subpoint is the angular distance the point is north or south of the equator. Declination is measured along an hour circle and ranges from 0° to 90° and corresponds to latitude (refer back to figure 11-5).

The hour circle from which east-west position is measured is the hour circle passing through the first point of Aries. The first point of Aries or vernal equinox is an unmarked point on the equator. It is defined as the point where the sun appears to cross the celestial equator from south to north. Though not absolutely stationary with relation to the stars, the first point of Aries changes position so slowly that it may be thought of as fixed for a period as long as a year. The symbol for the first point of Aries (ϒ) is the ancient symbol for the constellation of Aries, the ram.

SIDEREAL HOUR ANGLE (SHA). Sidereal Hour Angle (SHA) is the angular distance measured from the upper branch of the hour circle of Aries westward to the upper branch of the hour circle of the point in question (figure 11-14). It corresponds roughly to longitude on the earth. SHA is always measured westward, never eastward; hence, it may be any angle from 0° to 360°. (Longitude, of course, is measured eastward or westward and does not exceed 180°.)

Greenwich Hour Angle

The motions of celestial bodies, and the reasons why bodies within the solar system have constantly changing declinations, are discussed later in this section. For the present, however, it is sufficient to know that the sun is constantly changing in declination between certain values north and south of the equator. In the period of one year the sun crosses the equator twice—once when it goes from north to south declination, and once when it goes from south to north declination.

The point on the equator where the sun crosses it going from south to north is called the first point of Aries. If the first point of Aries can be established, all stars can be located from this point by means of declination and SHA.

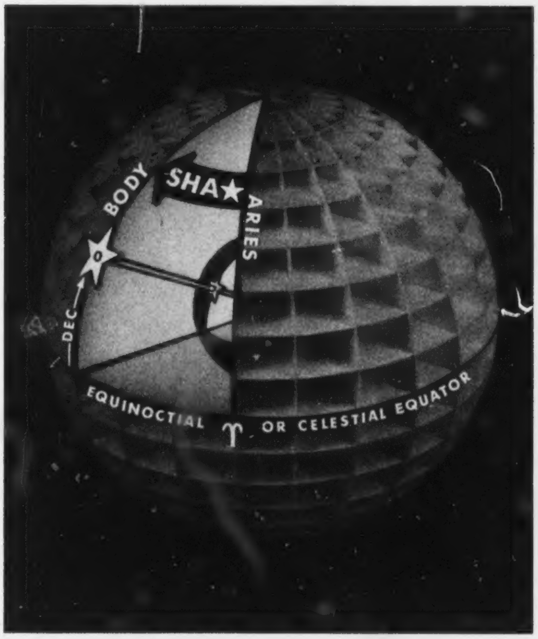


Figure 11-14. Sidereal Hour Angle (SHA)

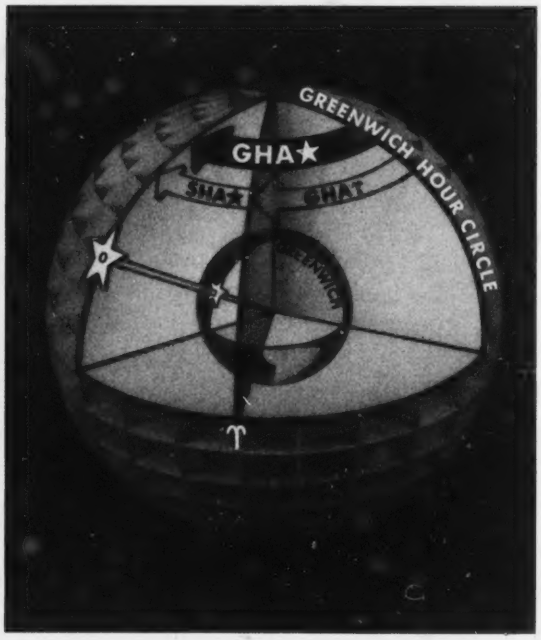


Figure 11-15. Greenwich Hour Angle (GHA)

The declination of a body equals the latitude of its subpoint. However, the apparent rotation of the celestial bodies causes the longitude of their subpoints to change continuously. Therefore, the SHA is of no value by itself in expressing the longitude of the subpoint. However, the longitude of the subpoint may be expressed by means of the Greenwich hour angle.

Greenwich hour angle (GHA) is the angular distance measured from the Greenwich meridian westward to the upper branch of the hour circle passing through the point. Since it is measured only westward, it is an angle from 0° to 360°. Thus, the GHA of a body is the west longitude of the subpoint if it is less than 180°. If it is more than 180°, GHA is 360°—east longitude.

From the *Air Almanac* the GHA of the sun, moon, planets, and Aries can be determined directly for any time. The GHAs of the navigational stars are not tabulated, but can be easily found. Since GHA of Aries is the angular distance from Greenwich west to Aries, and since the SHA of the star is the angular distance from Aries westward to the star, the GHA of Aries plus the SHA of the star equals the angular distance from Greenwich westward to the star, which is the GHA of the star as illustrated in figure 11-15.

Local Hour Angle

Local Hour angle (LHA) is the angular distance from the observer's celestial meridian westward to the upper branch of the hour circle through the body. As shown in figure 11-16, the LHA can also be measured at the pole from the observer's meridian westward, through 360° to the meridian through the subpoint, or as an arc of the equator.

The LHA of a body can be found by applying the local longitude to the GHA of the body. If the navigator is in west longitude, the LHA of a body is equal to the GHA of a body minus the west longitude. If the navigator is in east longitude, the LHA of the body equals the GHA of the body, plus the east longitude.

LHA★=GHA★—Longitude West
(or+Longitude East)

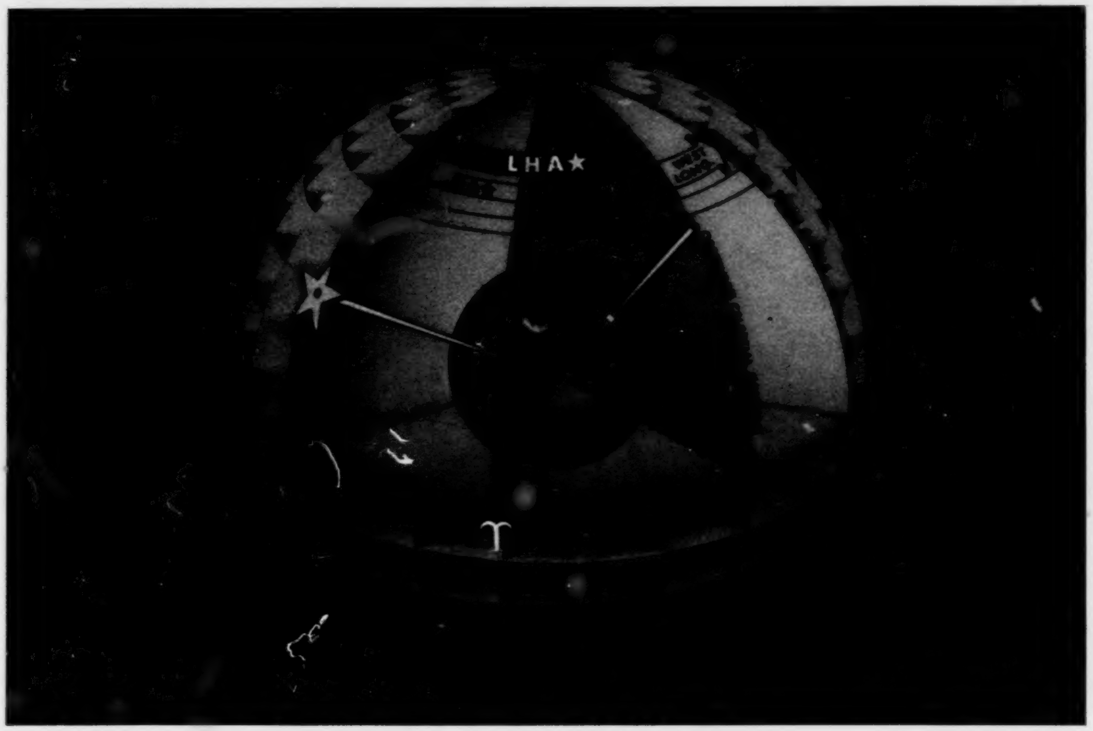


Figure 11-16. Local Hour Angle (LHA)

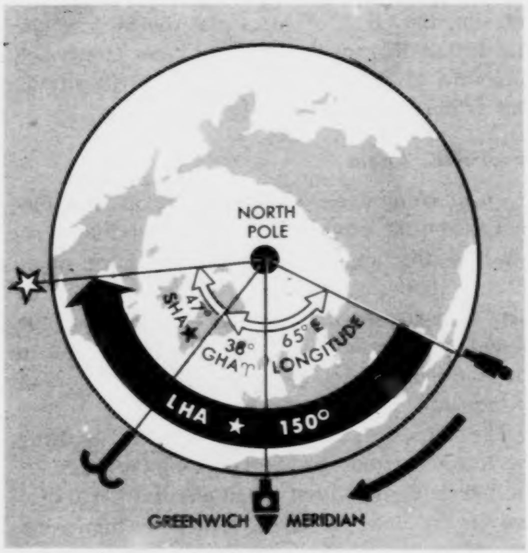


Figure 11-17. Time Diagram

Time Diagrams

When the navigator works with longitude and hour angles, a diagram may help him to understand their relationship. Such a diagram showing relationship of longitude and hour angle is called a *time diagram*. It will be helpful in learning the definitions and formulas.

A time diagram is an outline of the earth as seen from above the North Pole. It is constructed by drawing the equator as a circle with the pole at its center, and by drawing the meridians as straight lines radiating from the pole. Let the lower vertical radius represent the Greenwich meridian, thus fixing the positions of the other meridians. Draw the observer's meridian in its approximate position relative to Greenwich, and indicate the approximate positions of the body and Aries outside the circle, labeling the angles. Remember that west is clockwise.

Now the navigator has a picture of the whole situation. This should prevent him from making any error in using the formulas. For example,

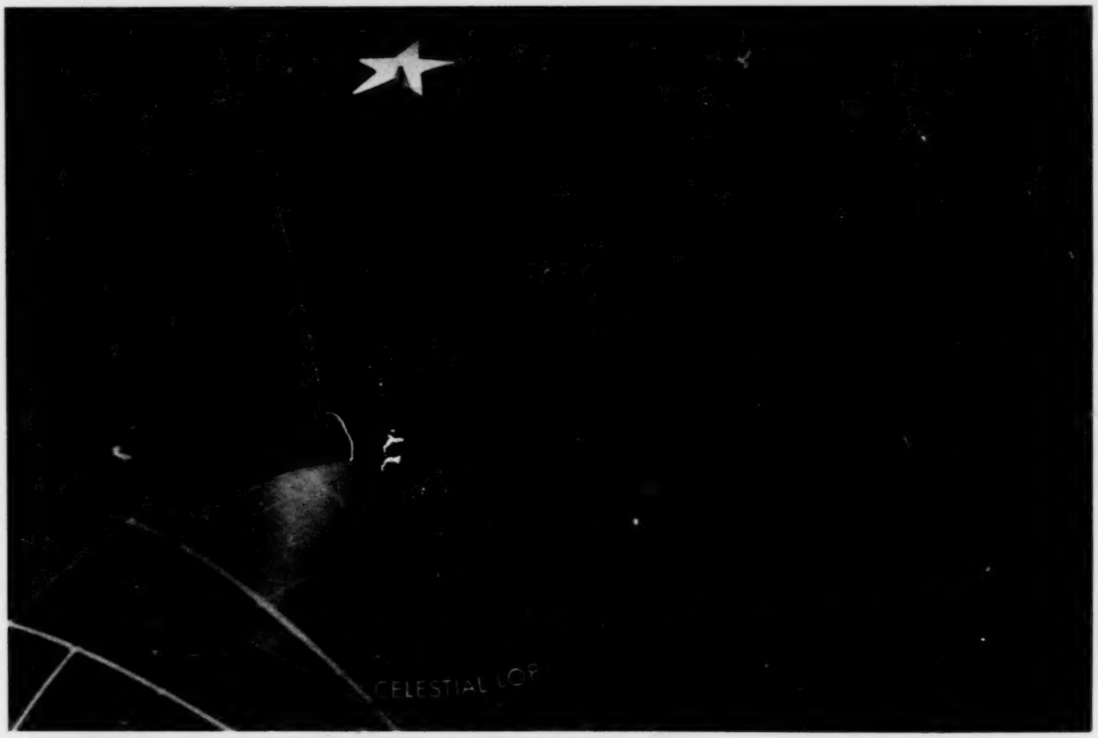


Figure 11-18. The Circle is a Celestial LOP

suppose he wants to find the LHA of a star, and the following information is known:

Longitude of his position	65° E
GHA ♈	38°
SHA ★	47°

The time diagram shows that LHA of the star (150°) is the sum of the three given values.

The time diagram can be simple, as the one shown in figure 11-17 or it can contain other items as well. In the chapter concerning time, the diagrams are used to show a variety of items.

ALTITUDE AND AZIMUTH

When a body is observed through a sextant, an angle is measured from which the distance of the observer's position from the subpoint of the body can be determined. Although this subpoint is continuously moving across the earth, its geographical position for the time of the sextant observation can be ascertained. Then, setting dividers at this distance as shown in figure 11-18 a circle can be scribed about the subpoint. Since this circle passes through all points at this distance from the subpoint, it must pass through the observer's position. Therefore, this circle is a *celestial LOP*. This is only a sketchy preview of the way a celestial LOP is obtained. Before taking out a sextant and shooting a celestial fix, the navigator must know what to measure with the sextant and how to determine the distance from the subpoint. Then he must know how to locate the position of the subpoint for the time of his observation.

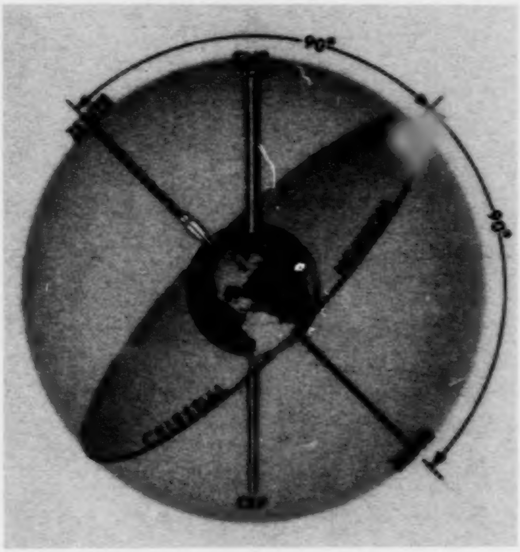


Figure 11-19. Celestial Horizon is 90° from Observer's Zenith and Nadir

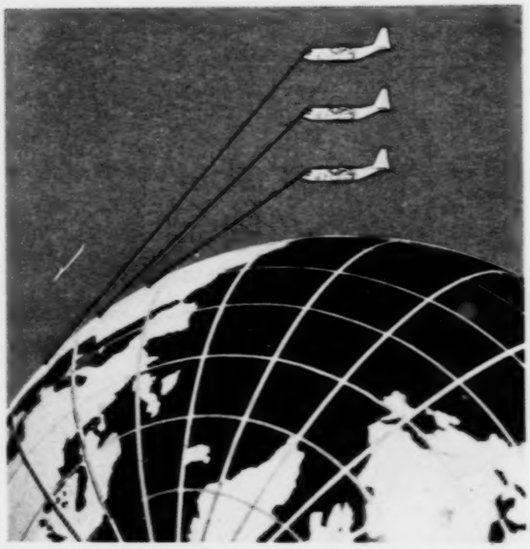


Figure 11-20. Visible Horizon Varies with Altitude

Horizons

The visual horizon is that plane tangent to the earth at the observer's position. A parallel plane passing through the center of the earth is the celestial horizon. The plane forming the celestial horizon is perpendicular to the observer's zenith-nadir axis. The celestial horizon divides the earth into two hemispheres. The upper hemisphere containing the observer's position is visible, whereas the lower is hidden from him by the earth. (See figure 11-19).

Many are familiar with the sea horizon or visible horizon—the line where sea and sky appear to meet. The position of the visible horizon depends on the height of the eye above the sea. If the eye is at the level of the sea, the visible horizon coincides with the celestial horizon, and only those bodies which are above the celestial horizon can be seen. If the observer is above the sea, the visible horizon is below the celestial horizon. If the navigator were in the aircraft depicted in figure 11-20, it can be seen that the higher the aircraft goes the lower the visible horizon will be and more bodies will be seen below the celestial hori-

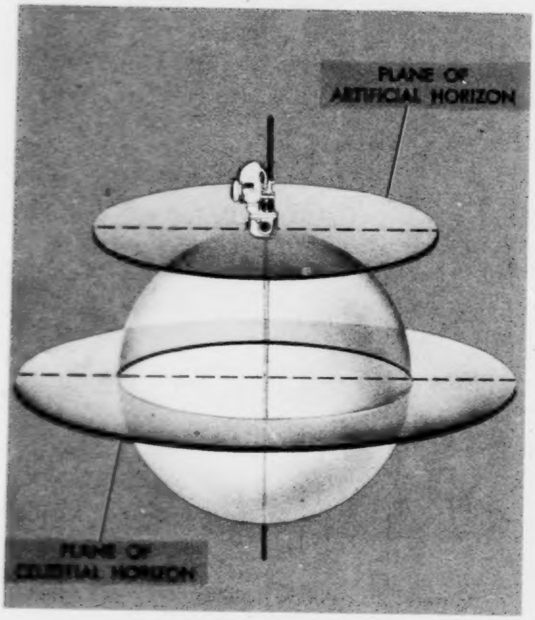

PLANE OF
ARTIFICIAL HORIZON
PLANE OF
CELESTIAL HORIZON

Figure 11-21. The Two Planes are Parallel

zon. On land, of course, the visible horizon is irregular because of the unevenness of the terrain.

The horizon most used by the air navigator is the bubble or artificial horizon. As in a carpenter's level, a bubble indicates the apparent vertical and horizontal. By means of the bubble, the navigator can level the sextant, and establish a reference plane parallel to the plane of the celestial horizon. This plane is the *artificial horizon.* The artificial horizon is established by the bubble in the sextant. Notice in figure 11-21 that the plane of the bubble horizon and the plane of the celestial horizon are parallel and are separated by the radius of the earth. In comparison with the vast distances to the celestial bodies, the radius of the earth is immeasurably small. Therefore, if two parallel circles on the earth are separated by a linear distance equal to the radius of the earth, these two circles must appear to coincide. Thus, the artificial horizon and the celestial horizon appear to coincide and can be considered identical.

Altitude

The geographical position of a celestial body can be determined for any time. To establish a celestial LOP, the observer's position relative to the geographical position of a celestial body must be ascertained. The factor which can be measured most conveniently, with some degree of accuracy, is the altitude of the body.

The *altitude of a celestial body* is its angular distance above the observer's celestial horizon. Altitude is measured from the horizon along the great circle passing through the observer's position and the body. In figure 11-22 the great circle passing through the observer's position is perpen-

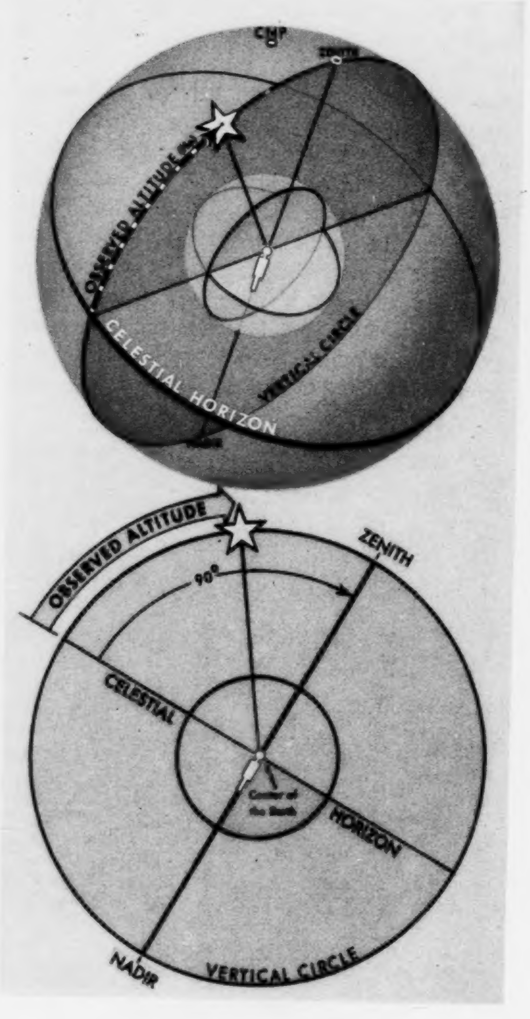

CNP
ZENITH
OBSERVED ALTITUDE
CELESTIAL HORIZON
VERTICAL CIRCLE
NADIR
OBSERVED ALTITUDE
ZENITH
90°
CELESTIAL
Center of the Earth
HORIZON
NADIR
VERTICAL CIRCLE

Figure 11-22. Measure Altitude from Celestial Horizon Along Vertical Circle

dicular to the horizon. Any great circle which passes through the observer's position and is perpendicular to the horizon is called a *vertical circle*. The altitude of a body can be measured with a sextant. The altitude read from the sextant is called *sextant altitude (Hs)*. However, because of certain errors in observation, small corrections must be applied to the Hs to obtain the actual altitude of the body above the celestial horizon. The sextant altitude (Hs), with these corrections applied, is called the *observed altitude (Ho)*.

Ho is the angle, or the arc of the vertical circle subtended by this angle, between the celestial horizon and the line of sight to the body. On the other hand, Ho is the angle which this arc subtends at the center of the earth, or the angle at the observer's position from the plane of the celestial horizon to the line of sight to the body. To measure this angle, the sextant must use some line or plane of reference whose relationship to the celestial horizon is known.

When the bubble sextant is level, it measures angles above the artificial or bubble horizon. Since the bubble horizon and the celestial horizon are considered to be identical, the arc from the bubble horizon to a body is equal to the arc from the celestial horizon to the body. Therefore, the bubble sextant measures altitude above the celestial horizon.

It may be hard to understand that the altitude of a body is the same whether it is measured at the surface of the earth from the artificial horizon or at the center of the earth from the celestial horizon. However, since these horizons are parallel, if the light rays from the body are parallel, the altitudes will be the same. Figure 11-23 shows that the angle of divergence between light rays arriving at different points on the earth is very small.

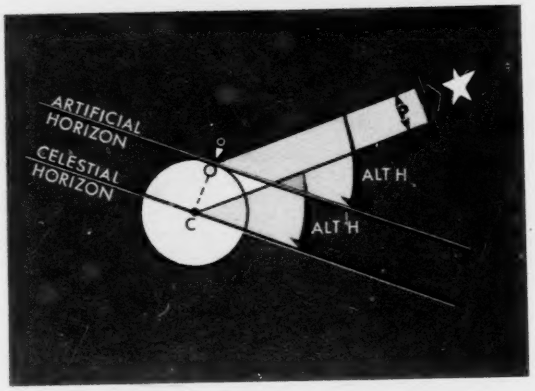


Figure 11-23. Parallel Lines Make Equal Angles with Parallel Planes

This angle between light rays is called *parallax*. In figure 11-24 parallax is shown at its maximum value; that is, when the observer and the subpoint are separated by 90°. In this situation, tan p is equal to OC (radius of the earth) over the distance C★. The radius of the earth is a very small distance compared to the distance to any of the stars. Thus, the angle p is very small. For the sun, one of the closest celestial bodies used in navigation, tan p equals 3940 divided by 93,000,000 or 0.000042. The angle p then equals approximately 9″ of arc or 0.15 nautical mile. This angle is so small that it is negligible. Therefore, for practical work, the observed altitudes from either the artificial or celestial horizon are the same.

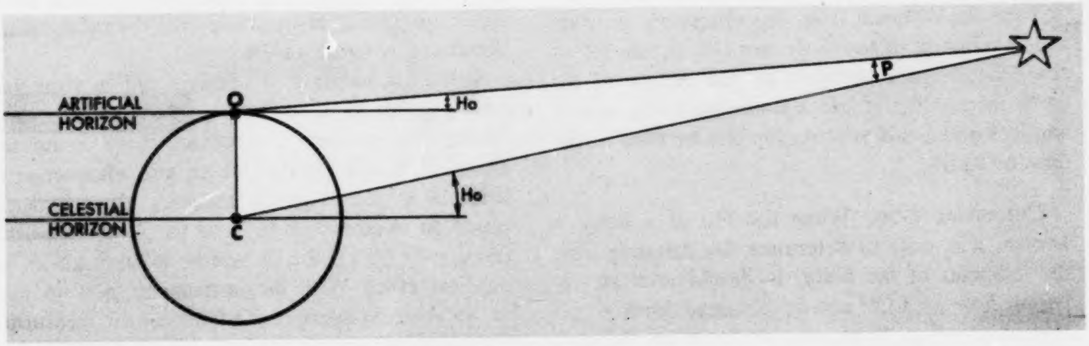


Figure 11-24. Parallax

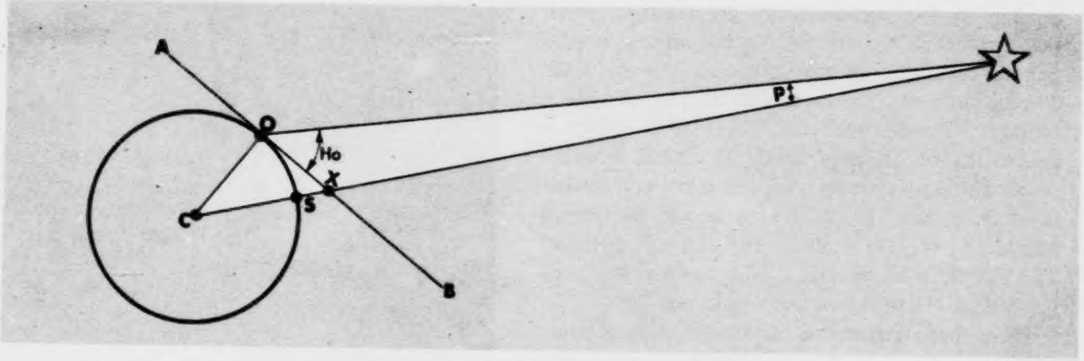


Figure 11-25. Finding Observed Altitude

OBSERVED ALTITUDE. There is a definite relationship between the Ho of a body and the distance of the observer from the subpoint. When the body is directly overhead, the Ho is 90°, and the subpoint and the observer's position are identical. When the Ho is 0°, the body is on the horizon and the subpoint is 90° (5400 NM) from the observer's position. This relationship is shown in the figure 11-25, where C is the center of the earth, AB is the observer's horizon, and S is the subpoint of the body. Since the sum of the angles in a triangle must equal 180°, the angle $OX\bigstar$ is equal to $180° - (Ho+p)$. The sum of the angles on a straight line is equal to 180°, so angle OXC is equal to $Ho+p$. The horizon AB being tangent to the earth at O is perpendicular to OC, a radius of the earth. Thus angle OCX is equal to $90° - (Ho+p)$. In the preceding discussion it was shown that angle p is negligible, so this angle becomes $90° - Ho$. The arc on the surface subtended by the angle OCX at the center of the earth is arc OS. This arc then is equal to $90° - Ho$.

Thus the distance from the observer's position to the subpoint of the body, arc OS, equals $90° - Ho$. Since angular distance on the surface of the earth in minutes of arc equals linear distance in nautical miles, this relationship can be used to determine LOPs.

CELESTIAL LOP. When the Ho of a body is known, it is easy to determine the distance from the subpoint of the body. It should now be apparent how an LOP can be obtained from a sextant observation. First, plot on the chart the geographical position of the body for the time of observation. Then, describe a circle about the subpoint with a radius equal to 90°—Ho. Since this circle passes through all points on the chart at the observer's known distance from the subpoint, his position must be on the circle. Therefore, the circle is his celestial LOP. A circle whose center is the subpoint of a body may be called a *circle of equal altitude* for that body. A celestial LOP is a circle of equal altitude. Previously the distance from subpoint of the body was discussed, now the direction of the body is considered.

True Azimuth

In celestial navigation, the direction of a body from an observer is called *true azimuth (Zn)*. The true azimuth of a celestial body corresponds exactly to the true bearing of an object located at the subpoint. The true azimuth of a celestial body is the angle measured at the observer's position from true north clockwise through 360° to the great circle arc joining his position with the subpoint, as illustrated in figure 11-26.

If the true azimuth of a body could be measured when its altitude is observed, a fix could be established. Unfortunately, however, there is no instrument in the aircraft which will measure true azimuth to the required accuracy. If a body is observed at an Ho of 40° and the Zn is measured incorrectly by 1°, the fix will be in error about 50 nautical miles. With the instruments now in use, an accurate fix cannot be established by measuring the altitude and azimuth of a single body, except in the case of a very high body (85° to 90°).

CELESTIAL FIX

Since a fix cannot be obtained from a single body, LOPs from two or more bodies must be crossed. The fix position is the intersection of the LOPs. A celestial LOP is a circle; however, as shown in figure 11-27, when two celestial LOPs are plotted, they intersect at two points, only one of which can be the observer's position. In practice, these two intersections usually are so far apart that dead reckoning removes all doubt as to which is the correct position.

Up to now, how to determine the observer's distance from the subpoint of a body by means of a sextant observation has been discussed. However, an LOP cannot be plotted until the position of the subpoint is established for the time of the observation. First, the navigator must understand how to position a body's subpoint.

The preceding discussion is merely a rough explanation of the manner in which a celestial fix

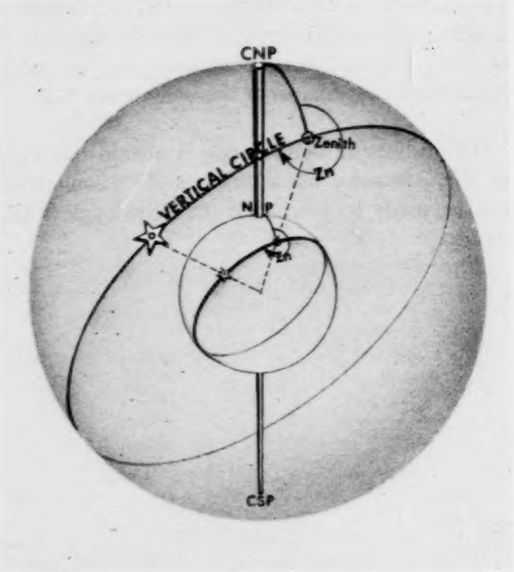


Figure 11-26. True Azimuth is Measured from True North

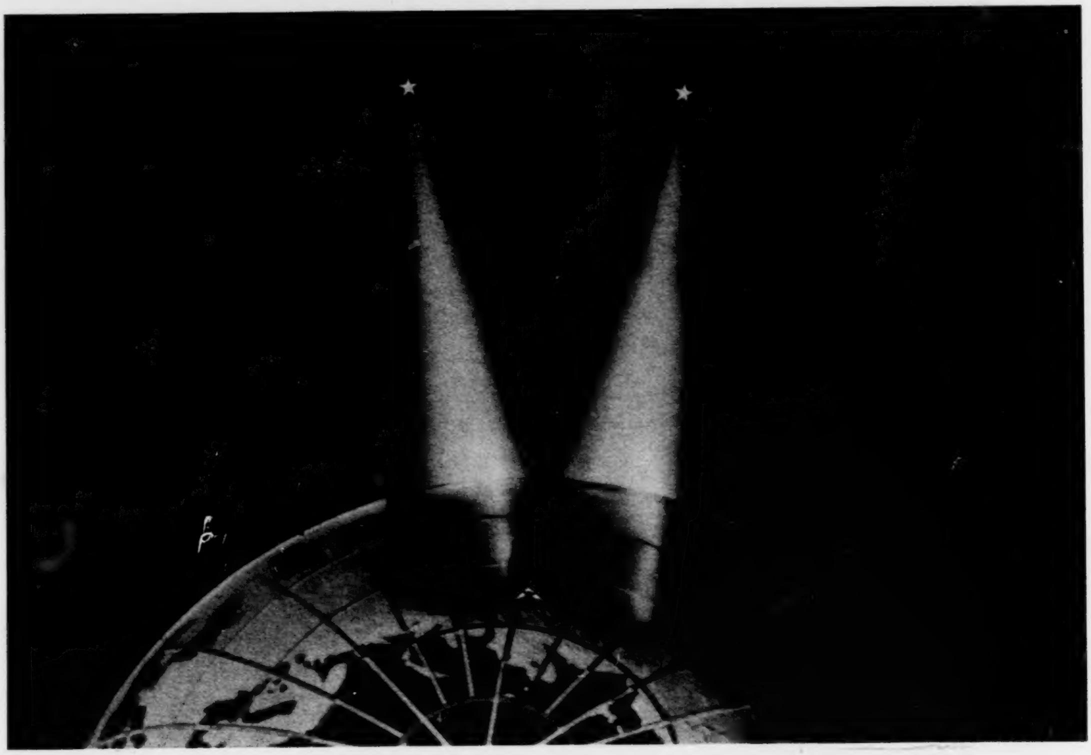


Figure 11-27. Celestial Fix

is determined. In establishing the fix, the navigator should determine the distance from the subpoint of the body. To do this it is necessary to determine the celestial coordinates of the body being used.

The declination of the body is always listed in the *Air Almanac,* but a few simple calculations must be made to determine the hour angle relationship.

Until the navigator is thoroughly familiar with the definitions and formulas, the time diagram previously explained will aid considerably in determining these relationships. The hour-circle and hour-angle system is used because the positions of the celestial bodies are a function of time. The material in the following chapter explains these motions and will help to clarify the celestial solution.

CHAPTER 12

Time

In celestial navigation, the position of the aircraft is determined by observing the celestial bodies. The apparent position of these bodies in respect to a point on the earth changes with time. Therefore, the determination of the position of the aircraft relies on exact timing of the observation. Thus, the navigator must have an understanding of the relationships of time, longitude, and hour angle.

Time is measured in terms of the rotation of the earth and the resulting apparent motions of the celestial bodies. Several different systems of measurement, each of which has a special use, are considered in this chapter.

Before getting into the actual discussion of the various kinds of time, there is one basic term that must be understood. That term is *transit*. The time at which a body passes the observer's meridian is called the time of transit. The observer's meridian is divided by the poles into halves. Notice in figure 12-1 that the upper branch is that half which contains the observer's position. The lower branch is the opposite half. Every day, because of the earth's rotation, every celestial body transits the upper and lower branches of the observer's meridian. As mentioned before, there are several kinds of time. The first presented here is solar time.

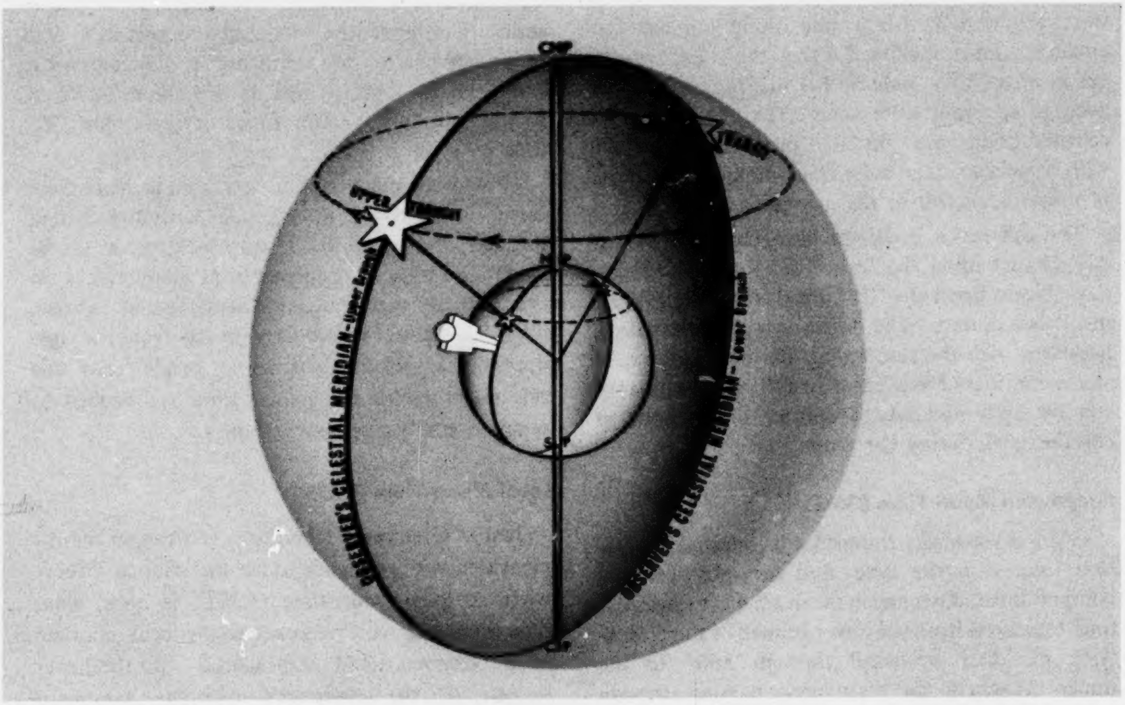

UPPER TRANSIT
TRANSIT
OBSERVER'S CELESTIAL MERIDIAN—Upper Branch
OBSERVER'S CELESTIAL MERIDIAN—Lower Branch

Figure 12-1. Transit is Caused by Earth's Rotation

APPARENT SOLAR TIME

The sun as seen in the sky is called the true sun, or apparent sun. Apparent solar time is time based upon the movement of the sun as it appears in the sky. It is, for example, the time indicated by a sundial.

Upper transit of the sun takes place at 1200 hours apparent time each day and lower transit at 2400 hours apparent time. Apparent time has one serious shortcoming as a basis for regulating man's activities, in that the sun does not appear to revolve around the earth at the same speed throughout the year. As a result, the apparent length of the day varies from day to day throughout the year, and a time piece would have to operate at different speeds at different times of the year if it were to indicate the correct apparent time. The difficulties involved in the use of apparent time led to the introduction of "mean time."

MEAN SOLAR TIME

A mean day is an artificial unit of constant length, based on the average of all apparent solar days over a period of years. Time for a mean day is measured with reference to a fictitious body, the mean sun, so designed that its hour circle moves westward at a constant rate along the celestial equator. Time reckoned using the mean sun is called *mean solar time* and is nearly equal to the average apparent solar time. The coordinates of celestial bodies are tabulated in the *Air Almanac* with respect to mean solar time, making it the time of primary interest to the navigator.

The difference in length between the apparent day (based upon the "true" sun) and the mean day (based upon the "fictitious" sun) is never as much as a minute. The differences are cumulative, however, with the result that the imaginary mean sun is considered to precede or follow the apparent sun by approximately a quarter of an hour at certain times during the year.

Greenwich Mean Time (GMT)

GMT is especially important in celestial navigation since it is the time used for most celestial computations. Greenwich mean time is mean solar time measured from the lower branch of the Greenwich meridian westward through 360° to the upper branch of the hour circle passing through the mean sun (see figure 12-2.) The mean sun transits the lower branch of the meridian of Greenwich at GMT 2400 (0000) each day and the upper branch at GMT 1200. The meridian at Greenwich is the logical selection for this reference, as it is the origin for the measurement of Greenwich hour angle and the reckoning of longitude. Consequently, celestial coordinates and other information are tabulated in almanacs with reference to GMT, GMT is sometimes referred to as Zulu time, Zebra time, or just plain "Z" time.

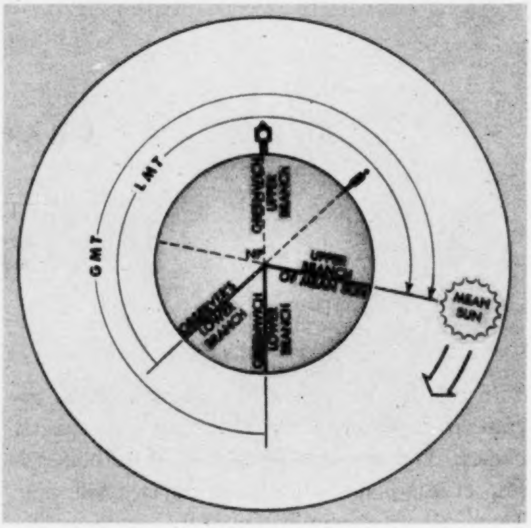


Figure 12-2. Measuring Greenwich Mean Time (GMT)

Greenwich mean time is not a convenient time for use in regulating the everyday activities of man throughout the world. If all clocks were set to GMT, the time of occurrences at many places on the earth of such natural phenomena as sunrise, noon, and sunset would vary greatly from the time normally associated with these events. For this reason, other kinds of solar time are needed to regulate man's everyday activities.

Local Mean Time (LMT)

Just as Greenwich mean time is mean solar time measured with reference to the meridian at Greenwich, so local mean time (LMT) is mean solar time measured with reference to the local meridian of an observer. LMT is measured from the lower branch of the observer's meridian westward through 360°, to the upper branch of the hour circle passing through the mean sun (refer to figure 12-2.) The mean sun transits the lower branch of the meridian of an observer at LMT 0000 (2400) and the upper branch at LMT 1200. Note that if an observer were at the Greenwich meridian, GMT would also be the LMT of the observer.

LMT is not used to regulate man's activities because LMT, being based on the meridian of each observer, varies continuously with longitude. This disadvantage of LMT has led to the introduction of *zone time* as the basis for governing routine activities. The navigator uses LMT only in certain cases, such as in the computations of such phenomena as sunrise, sunset, twilight, moonrise, and moonset at various latitudes along a given meridian.

Relationship of Time and Longitude

It has been established that the mean sun travels at a constant rate. Consequently, the mean sun will make two successive transits of the same meridian in 24 hours. Therefore, the mean sun travels an arc of 360° in 24 hours. The following relationship exists between time and arc.

Time	*Arc*
24 hours	360 degrees
1 hour	15 degrees
4 minutes	1 degree
1 minute	15 minutes
4 seconds	1 minute

Local time is the time at one particular meridian. Since the sun cannot transit two meridians simultaneously, no two meridians have exactly the same local time. The difference in time between two meridians is the time of the sun's passage from one meridian to the other. This time is proportional to the angular distance between the two meridians. Remember, that one hour is equivalent to 15°.

For example, if two meridians are 30° apart, their time differs by two hours. The local time is later at the easternmost of the two, since the sun has crossed its lower branch first and thus the day is older there. These statements hold true whether referring to the true sun or the mean sun. Figure 12-3 demonstrates that the sun crossed the lower branch of the meridian of observer #1 at 60° east longitude four hours before it crossed the lower branch of the Greenwich meridian (60 divided by 15) and six hours before it crossed the lower branch of the meridian of observer #2 at 30° west longitude (90 divided by 15). Therefore, the local time at 60° east longitude is later by the respective amounts.

Zone Time

It would be awkward to use the local time for every meridian. Every city would have its own time, to the great confusion of travelers. One standard time, such as GMT, could be used all over the world, but then in most longitudes the time would not have its usual relation to the sun's position in the sky. A compromise between the use of local time at every meridian and the use of one standard time over the world has been worked out in the system of standard time zones.

STANDARD TIME ZONE. The world has been divided into 24 zones, each zone being 15° of longitude in width. Each zone uses the LMT of its central meridian. Since the Greenwich meridian is the central meridian for one of the zones, and each zone is 15° or one hour wide, the time in each zone differs from GMT by an integral number of hours. The zones are designated by numbers from 0 to +12 and −12, each indicating the number of hours which must be added to *local zone*

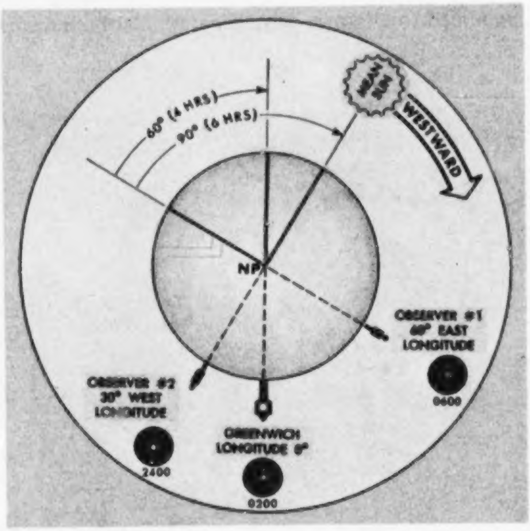


Figure 12-3. Local Time Differences at Different Longitudes

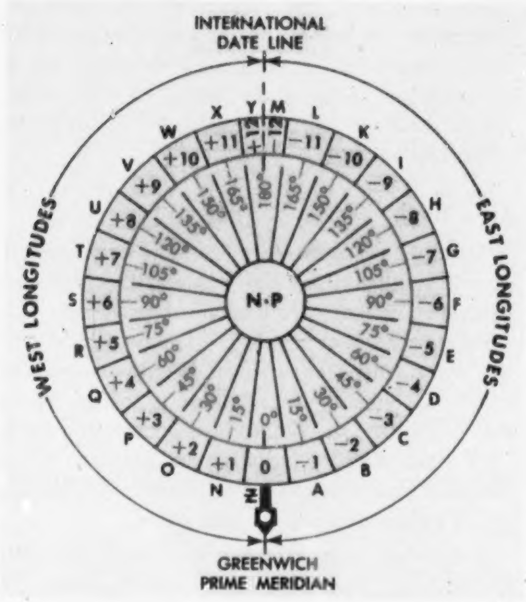

INTERNATIONAL DATE LINE
WEST LONGITUDES
EAST LONGITUDES
N·P
X Y M L K I H G F E D C B A N O P Q R S T U V W Z
+12 -12
+11 +10 +9 +8 +7 +6 +5 +4 +3 +2 +1 0 -1 -2 -3 -4 -5 -6 -7 -8 -9 -10 -11
180° 165° 150° 135° 120° 105° 90° 75° 60° 45° 30° 15° 0°
GREENWICH PRIME MERIDIAN

Figure 12-4. Standard Time Zones

time (LZT) to obtain GMT. Thus, since the time is earlier in the zones west of Greenwich, the numbers of these zones are plus, in those zones east of Greenwich, the numbers are minus (see figure 12-4). Sometimes zones are designated by letters of the alphabet for additional reference.

The zone boundaries have been considerably modified to conform with geographical boundaries for greater convenience. For example, in case a zone boundary passed through a city, it would be impractical to use the time of one zone in one part of the city and the time of the adjacent zone in the other part. In some countries, which overlap two or three zones, one time is used throughout. A few countries still use the local time of some one meridian.

DATE CHANGES AT MIDNIGHT. If the navigator were to travel west from Greenwich around the world, setting his watch back an hour for each time zone, he would have set his watch back a total of 24 hours when he got back to Greenwich and his date would be one day behind that of Greenwich. Conversely, traveling eastward, he would advance his watch a total of 24 hours and would gain a day in comparison with Greenwich.

To keep the records straight, it is necessary to add a day somewhere if going around the world to the west, and to lose a day if going around to the east. The 180° meridian was selected arbitrarily as the international date line—where a day is gained or lost. The date line follows the meridian except where it makes broad detours to avoid Eastern Siberia, the western Aleutian Islands, and several groups of islands in the South Pacific.

The local civil date changes at 2400 or midnight. Thus, the date changes as the mean sun transits the lower branch of the meridian.

Consider the situation in another way. The hour circle of the mean sun is divided in half at

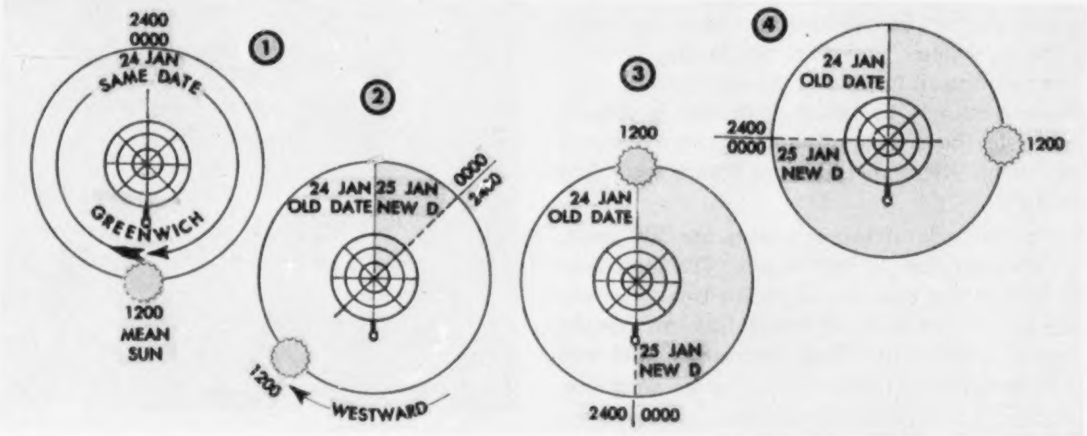
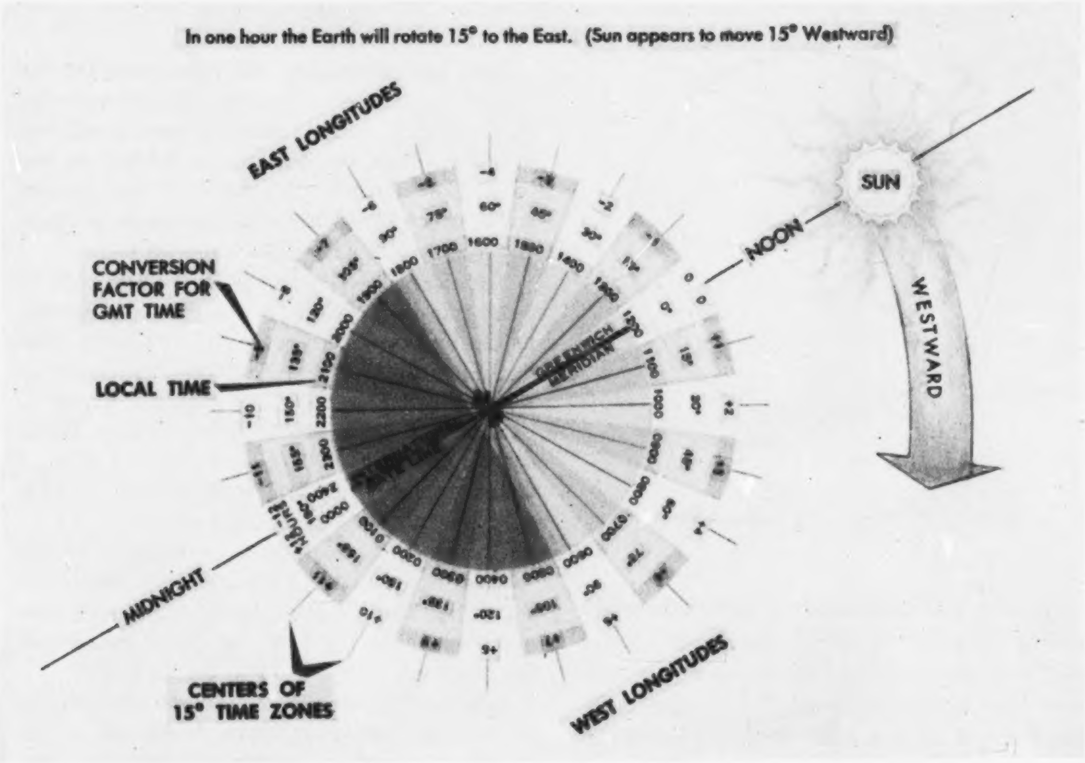

①
2400
0000
24 JAN
SAME DATE
GREENWICH
1200
MEAN
SUN
②
24 JAN
OLD DATE
25 JAN
NEW D
0000
2400
1200
WESTWARD
③
1200
24 JAN
OLD DATE
25 JAN
NEW D
2400 | 0000
④
24 JAN
OLD DATE
2400
0000
25 JAN
NEW D
1200

Figure 12-5. Zone Date Changes at Midnight Zone Time



In one hour the Earth will rotate 15° to the East. (Sun appears to move 15° Westward)

EAST LONGITUDES
CONVERSION FACTOR FOR GMT TIME
LOCAL TIME
MIDNIGHT
CENTERS OF 15° TIME ZONES
WEST LONGITUDES
NOON
SUN
WESTWARD
GREENWICH MERIDIAN
DATE LINE
-4
60°
1600
1700
1800
1900
2000
2100
2200
2300
2400
0000
1400
1300
1200
1100
1000
0900
0800
0700
0600
0500
0400
0300
0200
0100
-6
90°
75°
45°
30°
15°
0°
-2
-1
0
120°
135°
150°
165°
-10
-11
+12
-12
180°
165°
150°
135°
120°
105°
90°
75°
60°
45°
15°
30°
+1
+2
+3
+4
+6
+9
+10

Figure 12-6. Time Conversion

the poles. On the half away from the sun (the lower branch), it is always midnight local mean time. As the lower branch moves westward in figure 12-5, it pushes the old date before it and drags the new date after it. As the lower branch approaches the 180° meridian, the area of the old date decreases and the area of the new date increases. When the lower branch reaches the date line; that is, when the mean sun transits the Greenwich meridian, the old date is crowded out and the new date for that instant prevails in the world. Then, as the lower branch passes the date line, a newer date begins east of the lower branch, and the process starts all over again. (Because of the irregularities of the date line, the lower branch of the hour circle of the mean sun cannot coincide with the date line at any time. Therefore, strictly speaking, it is never the same date all over the world).

The zone date changes at midnight zone time, or when the lower branch of the mean sun transits the central meridian of the zone.

Time Conversion

The problem arises for the navigator to convert any given local time to Greenwich time or vice versa. This is done by use of a conversion factor. Practically speaking, it is not necessary for a person to remember all the conversion factors for all areas of the world, shown in figure 12-6. Since each time zone is 15° wide, the conversion factor can be determined by dividing local longitude by 15. If the remainder in the quotient is over 7°30′, then the next whole number should be used as the factor. The sign of the factor is *plus* if west longitude is used and *minus* if east. The conversion factor is then applied to the local time to obtain GMT.

NOTE: When going from local to GMT, remember, east is least and west is best.

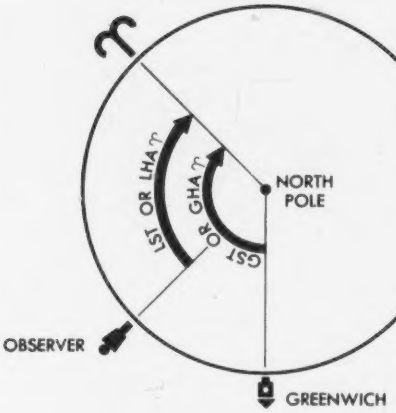


Figure 12-7. Greenwich Sidereal Time

Often the mathematical derivation obtained by dividing longitude by 15 is insufficient. Local residents might be using daylight saving time, or some areas because of geographical and political reasons might be in a different time zone. If the navigator checks the GMT at base operations before takeoff, he can use GMT throughout the entire flight.

The following are examples of determining GMT from local time when given longitude:

Example 1:

Given: Local time 2000 hours, 15 February
Local longitude, 137°15′W

Find: Conversion factor
GMT

1. Divide 137°15′ by 15. Quotient = 9, remainder 2°15′. Conversion factor is +9. (west-best-plus sign)

2. GMT = 2000 hrs + 9 = 2900 − 2400 = 0500 hrs, 16 February.

Example 2:

Given: Local time 0700 hrs, 30 June
Local longitude, 68°21′E

Find: Conversion factor
GMT

1. Divide 68°21′ by 15. Quotient = 4, remainder 8°21′. Conversion factor is −5. (east-least-minus sign)

2. GMT = 0700 − 5 = 0200 hrs, 30 June.

SIDEREAL TIME

Solar time is measured with reference to the true sun or the mean sun. Time may also be measured by the earth's rotation relative to some fixed point in space. Time so measured is *sidereal* or star time. The reference point used is the first point of Aries, which is considered as stationary in space, although it does have slight movement.

The sidereal day begins when the first point of Aries transits the *upper branch* of the observer's meridian. Local sidereal time (LST) is the number of hours that the first point of Aries has moved westward from the observer's meridian. Expressed in degrees, it is equal to the LHA of Aries. This is shown in figure 12-7. Local sidereal time at Greenwich is Greenwich sidereal time (GST), which is equivalent to the GHA of Aries.

Greenwich sidereal time, or GHA of Aries, specifies the position of the stars with relation to the earth. Thus, a given star is in the same position relative to the earth at the same sidereal time each day.

Sidereal time expressed in hours is not used in the celestial methods explained in this manual, although it is used in the form of GHA of Aries expressed in degrees. However, the concept of sidereal time should help in understanding the workings of the solar system.

NUMBER OF DAYS IN A YEAR

A year is the period of the earth's revolution about the sun. The number of days in the year is determined by the number of rotations of the earth during one revolution. If the earth were to revolve once eastward around the sun without rotating, the sun would appear to revolve once eastward around the earth. If the earth were to rotate once eastward without revolving, the sun would appear to revolve once westward around the earth. If the earth were to rotate once eastward while revolving once eastward around the sun, the sun would appear to remain overhead at one meridian for the same meridian would always be turned toward the sun. Therefore, it is obvious that one eastward revolution around the sun nullifies the apparent effect of one eastward rotation.

Actually the earth rotates eastward about 366.24 times in the course of its one yearly eastward revolution. The total effect of one revolution and

366.24 rotations is that the sun appears to revolve around the earth 365.24 times per year. Therefore, there are 365.24 solar days per year.

Since the sidereal day is measured with reference to a relatively fixed point, the length of the sidereal day is essentially the period of the earth's rotation. Therefore, the number of sidereal days in the year is equal to the number of rotations per year, which is 366.24.

Time, regardless of which type is considered, is measured with respect to either a body or fictitious point in space. Also, time has a definite relationship to longitude, namely, that 15° equal one hour. Since this relationship exists, celestial bodies can be positioned with reference to time.

NAVIGATOR'S USE OF TIME

The navigator makes direct use of three different kinds of time. These are Greenwich mean time, GMT; local mean time, LMT; and zone time, ZT. All three are based upon the motions of the fictitious "mean sun." The mean sun is considered to revolve about the earth at the average rate of the "apparent sun," making one complete revolution in 24 hours.

The reckoning of time is based upon the motion of the sun relative to a given meridian, the time being 2400-0000 at lower transit and 1200 at upper transit. In Greenwich mean time, the reference meridian is that of Greenwich; in local mean time, the reference meridian is that of a given place; in zone time, the reference meridian is the standard meridian of a given zone.

The difference between two times is equal to the difference of longitude of their reference meridians, expressed in units of time. GMT differs from LMT by the longitude of the place; GMT differs from ZT by the longitude of the standard meridian of the zone; LMT differs from ZT by the difference of longitude between the standard meridian of the zone and the meridian of the place. In applying a time difference, a place which is east of another place has a later time than that place, and a place which is west of another place has an earlier time than that place. In interconverting ZT and GMT, the navigator makes use of zone description in applying these rules. The ZD (zone difference) of a zone is the time difference between its standard meridian and GMT, and it is given a sign to indicate the correction to ZT to obtain GMT. The sign is plus (+) for places in west longitude and minus (—) for places in east longitude.

AIR ALMANAC

Although the *Air Almanac* contains a variety of astronomical data needed in navigation, most of it is devoted to the tabulation of the GHA of Aries, and the GHA and Declination of the sun, the three navigational planets most favorably located for observation, and the moon. Enter the daily pages, which are arranged in calendar form, with Greenwich date and GMT to extract the GHA and Declination (Dec) of a celestial body.

Finding GHA and Dec of the Sun

The GHA of the sun is listed for 10 minute intervals on each daily sheet. If the time of the observation is listed, read the GHA and Dec directly under the proper column opposite the time.

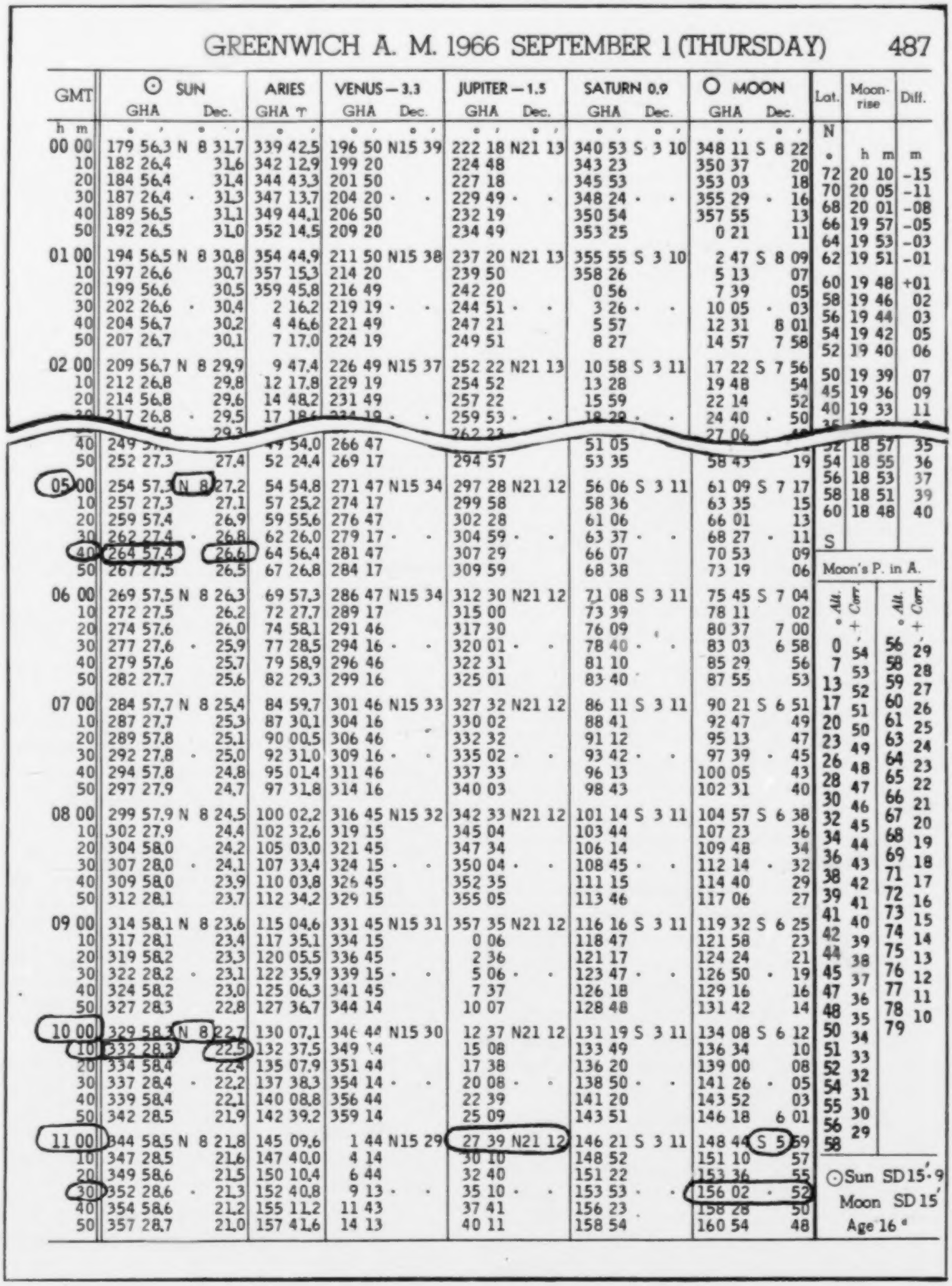
For example, find the GHA and Dec of the sun at GMT 0540 on 1 Sep 66. Refer to figure 12-8. The GHA is 264°—57′.4 and Dec is N 8°—26′.6. *NOTE: For use with the astrotracker, the GHA and Dec are given to 0′.1′ with the decimal in smaller type. For general use, it suffices to ignore this decimal instead of rounding-off in the normal way. A small additional error, never exceeding 0′.5′ arises, if, as recommended, the decimal in smaller type is ignored rather than rounded-off. This error can be avoided by rounding-off the tabulated values.*

Therefore, in this example the GHA is 264°—57′ and the Dec is N 8°—27′. To convert these values to the geographical coordinates of the subpoint for the time of the observation, latitude is 8°—27′ north. When GHA is greater than 180°, subtract it from 360° to get east longitude, therefore longitude in this example is (360°—264°57′) 95°03′E.

When an observation is made at a time not listed, make the main entry for the time immediately before that of the GMT required. Then use the table marked "Interpolation of GHA" to determine the increment to be added to GHA (see figure 12-9).

This table is conveniently located both inside the front cover of the almanac and on the back of the star chart.

On 1 September 1966, the sun is observed at 1012 GMT. What is the GHA and Declination?



GREENWICH A. M. 1966 SEPTEMBER 1 (THURSDAY) 487

GMT	⊙ SUN GHA	SUN Dec.	ARIES GHA ♈	VENUS—3.3 GHA	VENUS Dec.	JUPITER—1.5 GHA	JUPITER Dec.	SATURN 0.9 GHA	SATURN Dec.	○ MOON GHA	MOON Dec.
h m	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
00 00	179 56.3	N 8 31.7	339 42.5	196 50	N15 39	222 18	N21 13	340 53	S 3 10	348 11	S 8 22
10	182 26.4	31.6	342 12.9	199 20		224 48		343 23		350 37	20
20	184 56.4	31.4	344 43.3	201 50		227 18		345 53		353 03	18
30	187 26.4	· 31.3	347 13.7	204 20 ·	·	229 49 ·	·	348 24 ·	·	355 29	· 16
40	189 56.5	31.1	349 44.1	206 50		232 19		350 54		357 55	13
50	192 26.5	31.0	352 14.5	209 20		234 49		353 25		0 21	11
01 00	194 56.5	N 8 30.8	354 44.9	211 50	N15 38	237 20	N21 13	355 55	S 3 10	2 47	S 8 09
10	197 26.6	30.7	357 15.3	214 20		239 50		358 26		5 13	07
20	199 56.6	30.5	359 45.8	216 49		242 20		0 56		7 39	05
30	202 26.6	· 30.4	2 16.2	219 19 ·	·	244 51 ·	·	3 26 ·	·	10 05	· 03
40	204 56.7	30.2	4 46.6	221 49		247 21		5 57		12 31	8 01
50	207 26.7	30.1	7 17.0	224 19		249 51		8 27		14 57	7 58
02 00	209 56.7	N 8 29.9	9 47.4	226 49	N15 37	252 22	N21 13	10 58	S 3 11	17 22	S 7 56
10	212 26.8	29.8	12 17.8	229 19		254 52		13 28		19 48	54
20	214 56.8	29.6	14 48.2	231 49		257 22		15 59		22 14	52
30	217 26.8	· 29.5	17 18	·	·	259 53 ·	·	18 29 ·	·	24 40	· 50
		29.3				262 23				27 06	
40	249 5		49 54.0	266 47				51 05			
50	252 27.3	27.4	52 24.4	269 17		294 57		53 35		58 43	19
05 00	254 57.3	N 8 27.2	54 54.8	271 47	N15 34	297 28	N21 12	56 06	S 3 11	61 09	S 7 17
10	257 27.3	27.1	57 25.2	274 17		299 58		58 36		63 35	15
20	259 57.4	26.9	59 55.6	276 47		302 28		61 06		66 01	13
30	262 27.4	· 26.8	62 26.0	279 17 ·	·	304 59 ·	·	63 37 ·	·	68 27	· 11
40	264 57.4	26.6	64 56.4	281 47		307 29		66 07		70 53	09
50	267 27.5	26.5	67 26.8	284 17		309 59		68 38		73 19	06
06 00	269 57.5	N 8 26.3	69 57.3	286 47	N15 34	312 30	N21 12	71 08	S 3 11	75 45	S 7 04
10	272 27.5	26.2	72 27.7	289 17		315 00		73 39		78 11	02
20	274 57.6	26.0	74 58.1	291 46		317 30		76 09		80 37	7 00
30	277 27.6	· 25.9	77 28.5	294 16 ·	·	320 01 ·	·	78 40 ·	·	83 03	6 58
40	279 57.6	25.7	79 58.9	296 46		322 31		81 10		85 29	56
50	282 27.7	25.6	82 29.3	299 16		325 01		83 40		87 55	53
07 00	284 57.7	N 8 25.4	84 59.7	301 46	N15 33	327 32	N21 12	86 11	S 3 11	90 21	S 6 51
10	287 27.7	25.3	87 30.1	304 16		330 02		88 41		92 47	49
20	289 57.8	25.1	90 00.5	306 46		332 32		91 12		95 13	47
30	292 27.8	· 25.0	92 31.0	309 16 ·	·	335 02 ·	·	93 42 ·	·	97 39	· 45
40	294 57.8	24.8	95 01.4	311 46		337 33		96 13		100 05	43
50	297 27.9	24.7	97 31.8	314 16		340 03		98 43		102 31	40
08 00	299 57.9	N 8 24.5	100 02.2	316 45	N15 32	342 33	N21 12	101 14	S 3 11	104 57	S 6 38
10	302 27.9	24.4	102 32.6	319 15		345 04		103 44		107 23	36
20	304 58.0	24.2	105 03.0	321 45		347 34		106 14		109 48	34
30	307 28.0	· 24.1	107 33.4	324 15 ·	·	350 04 ·	·	108 45 ·	·	112 14	· 32
40	309 58.0	23.9	110 03.8	326 45		352 35		111 15		114 40	29
50	312 28.1	23.7	112 34.2	329 15		355 05		113 46		117 06	27
09 00	314 58.1	N 8 23.6	115 04.6	331 45	N15 31	357 35	N21 12	116 16	S 3 11	119 32	S 6 25
10	317 28.1	23.4	117 35.1	334 15		0 06		118 47		121 58	23
20	319 58.2	23.3	120 05.5	336 45		2 36		121 17		124 24	21
30	322 28.2	· 23.1	122 35.9	339 15 ·	·	5 06 ·	·	123 47 ·	·	126 50	· 19
40	324 58.2	23.0	125 06.3	341 45		7 37		126 18		129 16	16
50	327 28.3	22.8	127 36.7	344 14		10 07		128 48		131 42	14
10 00	329 58.3	N 8 22.7	130 07.1	346 44	N15 30	12 37	N21 12	131 19	S 3 11	134 08	S 6 12
10	332 28.3	22.5	132 37.5	349 14		15 08		133 49		136 34	10
20	334 58.4	22.4	135 07.9	351 44		17 38		136 20		139 00	08
30	337 28.4	· 22.2	137 38.3	354 14 ·	·	20 08 ·	·	138 50 ·	·	141 26	· 05
40	339 58.4	22.1	140 08.8	356 44		22 39		141 20		143 52	03
50	342 28.5	21.9	142 39.2	359 14		25 09		143 51		146 18	6 01
11 00	344 58.5	N 8 21.8	145 09.6	1 44	N15 29	27 39	N21 12	146 21	S 3 11	148 44	S 5 59
10	347 28.5	21.6	147 40.0	4 14		30 10		148 52		151 10	57
20	349 58.6	21.5	150 10.4	6 44		32 40		151 22		153 36	55
30	352 28.6	· 21.3	152 40.8	9 13 ·	·	35 10 ·	·	153 53 ·	·	156 02	· 52
40	354 58.6	21.2	155 11.2	11 43		37 41		156 23		158 28	50
50	357 28.7	21.0	157 41.6	14 13		40 11		158 54		160 54	48

Lat.	Moon-rise	Diff.
N		
°	h m	m
72	20 10	−15
70	20 05	−11
68	20 01	−08
66	19 57	−05
64	19 53	−03
62	19 51	−01
60	19 48	+01
58	19 46	02
56	19 44	03
54	19 42	05
52	19 40	06
50	19 39	07
45	19 36	09
40	19 33	11
52	18 57	35
54	18 55	36
56	18 53	37
58	18 51	39
60	18 48	40
S		

Moon's P. in A.

° Alt.	′ + Corr.	° Alt.	′ + Corr.
0	54	56	29
7	53	58	28
13	52	59	27
17	51	60	26
20	50	61	25
23	49	63	24
26	48	64	23
28	47	65	22
30	46	66	21
32	45	67	20
34	44	68	19
36	43	69	18
38	42	71	17
39	41	72	16
41	40	73	15
42	39	74	14
44	38	75	13
45	37	76	12
47	36	77	11
48	35	78	10
50	34	79	
51	33		
52	32		
54	31		
55	30		
56	29		
58			

⊙ Sun SD 15′.9

Moon SD 15′

Age 16 ᵈ

Figure 12-8. Daily Page from Air Almanac

INTERPOLATION OF G.H.A.

Increment to be added for intervals of G.M.T. to G.H.A. of:
Sun, Aries (♈) and planets; Moon.

SUN, etc.		MOON	SUN, etc.		MOON	SUN, etc.		MOON
m s	° ′	m s	m s	° ′	m s	m s	° ′	m s
00 00		00 00	03 17		03 25	06 37		06 52
	0 00			0 50			1 40	
01		00 02	21		03 29	41		06 56
	0 01			0 51			1 41	
05		00 06	25		03 33	45		07 00
	0 02			0 52			1 42	
09		00 10	29		03 37	49		07 04
	0 03			0 53			1 43	
13		00 14	33		03 41	53		07 08
	0 04			0 54			1 44	
17		00 18	37		03 45	06 57		07 13
	0 05			0 55			1 45	
21		00 22	41		03 49	07 01		07 17
	0 06			0 56			1 46	
25		00 26	45		03 54	05		07 21
	0 07			0 57			1 47	
29		00 31	49		03 58	09		07 25
	0 08			0 58			1 48	
33		00 35	53		04 02	13		07 29
	0 09			0 59			1 49	
37		00 39	03 57		04 06	17		07 33
	0 10			1 00			1 50	
41		00 43	04 01		04 10	21		07 37
	0 11			1 01			1 51	
45		00 47	05		04 14	25		07 42
	0 12			1 02			1 52	
49		00 51	09		04 19	29		07 46
	0 13			1 03			1 53	
53		00 55	13		04 23	33		07 50
	0 14			1 04			1 54	
00 57		01 00	17		04 27	37		07 54
	0 15			1 05			1 55	
01 01		01 04	21		04 31	41		07 58
	0 16			1 06			1 56	
05		01 08	25		04 35	45		08 02
	0 17			1 07			1 57	
09		01 12	29		04 39	49		08 06
	0 18			1 08			1 58	
13		01 16	33		04 43	53		08 11
	0 19			1 09			1 59	
17		01 20	37		04 48	07 57		08 15
	0 20			1 10			2 00	
21		01 24	41		04 52	08 01		08 19
	0 21			1 11			2 01	
25		01 29	45		04 56	05		08 23
	0 22			1 12			2 02	
29		01 33	49		05 00	09		08 27
	0 23			1 13			2 03	
33		01 37	53		05 04	13		08 31
	0 24			1 14			2 04	
37		01 41	04 57		05 08	17		08 35
	0 25			1 15			2 05	
41		01 45	05 01		05 12	21		08 40
	0 26			1 16			2 06	
45		01 49	05		05 17	25		08 44
	0 27			1 17			2 07	
49		01 53	09		05 21	29		08 48
	0 28			1 18			2 08	
53		01 58	13		05 25	33		08 52
	0 29			1 19			2 09	
01 57		02 02	17		05 29	37		08 56
	0 30			1 20			2 10	
02 01		02 06	21		05 33	41		09 00
	0 31			1 21			2 11	
05		02 10	25		05 37	45		09 04
	0 32			1 22			2 12	
09		02 14	29		05 41	49		09 09
	0 33			1 23			2 13	
13		02 18	33		05 46	53		09 13
	0 34			1 24			2 14	
17		02 22	37		05 50	08 57		09 17
	0 35			1 25			2 15	
21		02 27	41		05 54	09 01		09 21
	0 36			1 26			2 16	
25		02 31	45		05 58	05		09 25
	0 37			1 27			2 17	
29		02 35	49		06 02	09		09 29
	0 38			1 28			2 18	
33		02 39	53		06 06	13		09 33
	0 39			1 29			2 19	
37		02 43	05 57		06 10	17		09 38
	0 40			1 30			2 20	
41		02 47	06 01		06 15	21		09 42
	0 41			1 31			2 21	
45		02 51	05		06 19	25		09 46
	0 42			1 32			2 22	
49		02 56	09		06 23	29		09 50
	0 43			1 33			2 23	
53		03 00	13		06 27	33		09 54
	0 44			1 34			2 24	
02 57		03 04	17		06 31	37		09 58
	0 45			1 35			2 25	
03 01		03 08	21		06 35	41		10 00
	0 46			1 36			2 26	
05		03 12	25		06 39	45		
	0 47			1 37			2 27	
09		03 16	29		06 44	49		
	0 48			1 38			2 28	
13		03 20	33		06 48	53		
	0 49			1 39			2 29	
17		03 25	37		06 52	09 57		
	0 50			1 40			2 30	
03 21		03 29	06 41		06 56	10 00		

Figure 12-9. Interpolation of GHA, Air Almanac

Turning to the A.M. page for 1 September 1966 (figure 12-8), the GHA listed for 1010 is 332°—28′. The observation is for a time two minutes after the listed time. In the "Interpolation of GHA" table (figure 12-9), the correction listed for two minutes of time is 30′ of arc. By adding this correction to the listed GHA, the GHA of the sun for the exact time of the observation is 332°—58′. The Dec for the same time is N 8°—23′. Thus at the time of the observation, the subpoint of the sun is at latitude 8°—23′ North, longitude (360°—332° 58′) 027°—02′ East.

NOTE: By use of a table found in H.O. 249 Vol II (Sight Reduction Tables) the GHA and Declination of the sun may be found without using the Air Almanac. Any error is unlikely to exceed 2′.

Finding GHA and Dec of a Planet

GHA and Dec of a planet can be obtained in almost the same way as GHA and Dec of the sun. Notice that the declination of a planet changes slowly, therefore it is recorded only at hourly intervals. The Dec listed for the hour is used for the entire hour.

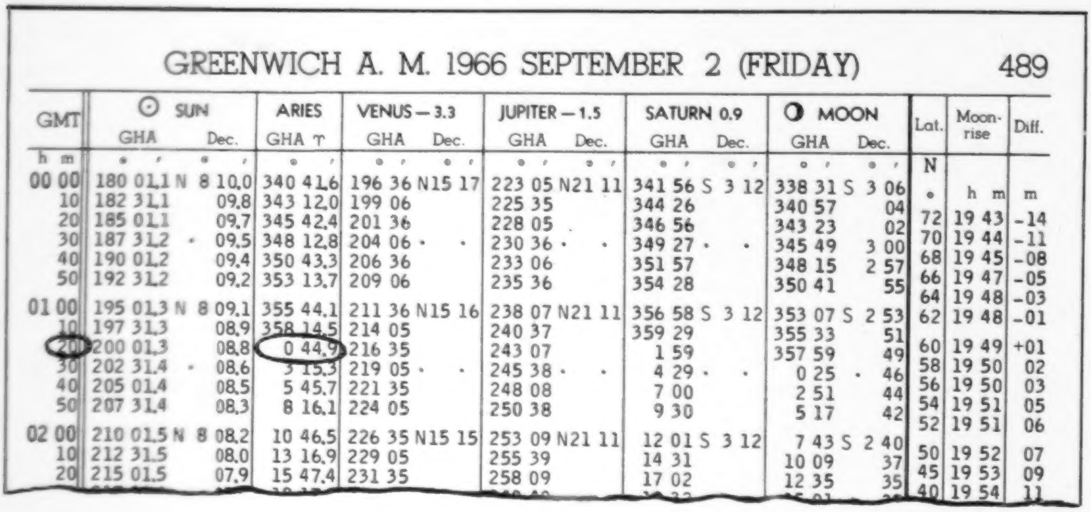
For 1 September 1966, find the GHA and Dec of Jupiter at 1109 GMT. Enter the correct daily page (see figure 12-8) for the time of 1100 GMT. The GHA and Dec for 1100 GMT is 27°—39′ GHA and N 21°—12′ Dec. Enter the Interpolation of GHA table under sun, etc, (figure 12-9) and obtain the adjustment to be added for nine minutes. For a nine-minute interval of GMT the increment to be added is 2°—15′. Therefore, GHA is 29°—54′. The subpoint of Jupiter at the time of the observation is at latitude 21°—12′ N, longitude 29°—54′ W.

Finding GHA and Dec of Moon

The moon moves across the sky at a different rate than the sun and planets; consequently, its GHA and Dec change differently; therefore, the declination is given at 10-minute intervals. In the interpolation tables for the GHA, separate values on the *right* are used for the moon.

The tables are arranged as critical tables, and the increment is found opposite the interval (in the left-hand column for the sun, Aries, and planets; in the right-hand column for the moon) in which the difference of GMT occurs. If the difference (e.g., 06ᵐ31ˢ for the moon) is an exact tabular value, the upper of the two possible increments (i.e., 1°34′) should be taken. This rule applies generally to all critical tables.

On 1 September 1966, the moon is observed at 1136 GMT. The following information is extracted from the *Air Almanac* (see figures 12-8 and 12-9):

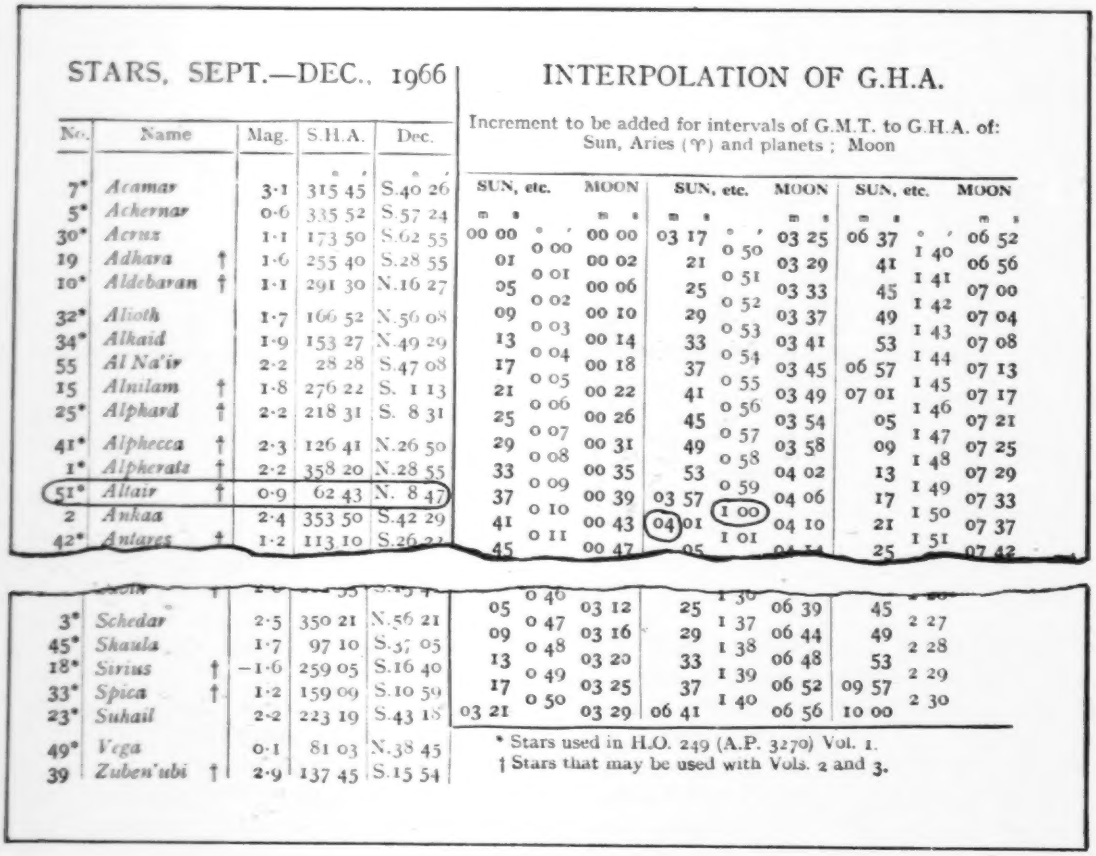


GREENWICH A. M. 1966 SEPTEMBER 2 (FRIDAY) 489

GMT	☉ SUN GHA	Dec.	ARIES GHA ♈	VENUS — 3.3 GHA	Dec.	JUPITER — 1.5 GHA	Dec.	SATURN 0.9 GHA	Dec.	◑ MOON GHA	Dec.
h m	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
00 00	180 01.1	N 8 10.0	340 41.6	196 36	N15 17	223 05	N21 11	341 56	S 3 12	338 31	S 3 06
10	182 31.1	09.8	343 12.0	199 06		225 35		344 26		340 57	04
20	185 01.1	09.7	345 42.4	201 36		228 05		346 56		343 23	02
30	187 31.2	· 09.5	348 12.8	204 06 ·	·	230 36 ·	·	349 27 ·	·	345 49	3 00
40	190 01.2	09.4	350 43.3	206 36		233 06		351 57		348 15	2 57
50	192 31.2	09.2	353 13.7	209 06		235 36		354 28		350 41	55
01 00	195 01.3	N 8 09.1	355 44.1	211 36	N15 16	238 07	N21 11	356 58	S 3 12	353 07	S 2 53
10	197 31.3	08.9	358 14.5	214 05		240 37		359 29		355 33	51
20	200 01.3	08.8	0 44.9	216 35		243 07		1 59		357 59	49
30	202 31.4	· 08.6	3 15.3	219 05 ·	·	245 38 ·	·	4 29 ·	·	0 25	· 46
40	205 01.4	08.5	5 45.7	221 35		248 08		7 00		2 51	44
50	207 31.4	08.3	8 16.1	224 05		250 38		9 30		5 17	42
02 00	210 01.5	N 8 08.2	10 46.5	226 35	N15 15	253 09	N21 11	12 01	S 3 12	7 43	S 2 40
10	212 31.5	08.0	13 16.9	229 05		255 39		14 31		10 09	37
20	215 01.5	07.9	15 47.4	231 35		258 09		17 02		12 35	35

Lat.	Moon-rise	Diff.
N °	h m	m
72	19 43	-14
70	19 44	-11
68	19 45	-08
66	19 47	-05
64	19 48	-03
62	19 48	-01
60	19 49	+01
58	19 50	02
56	19 50	03
54	19 51	05
52	19 51	06
50	19 52	07
45	19 53	09
40	19 54	11

Figure 12-10. GHA of Aries Obtained from Air Almanac



STARS, SEPT.—DEC., 1966

No.	Name		Mag.	S.H.A.	Dec.
				° ′	° ′
7*	*Acamar*		3·1	315 45	S.40 26
5*	*Achernar*		0·6	335 52	S.57 24
30*	*Acrux*		1·1	173 50	S.62 55
19	*Adhara*	†	1·6	255 40	S.28 55
10*	*Aldebaran*	†	1·1	291 30	N.16 27
32*	*Alioth*		1·7	166 52	N.56 08
34*	*Alkaid*		1·9	153 27	N.49 29
55	*Al Na'ir*		2·2	28 28	S.47 08
15	*Alnilam*	†	1·8	276 22	S. 1 13
25*	*Alphard*	†	2·2	218 31	S. 8 31
41*	*Alphecca*	†	2·3	126 41	N.26 50
1*	*Alpheratz*	†	2·2	358 20	N.28 55
51*	*Altair*	†	0·9	62 43	N. 8 47
2	*Ankaa*		2·4	353 50	S.42 29
42*	*Antares*	†	1·2	113 10	S.26
3*	*Schedar*		2·5	350 21	N.56 21
45*	*Shaula*		1·7	97 10	S.37 05
18*	*Sirius*	†	−1·6	259 05	S.16 40
33*	*Spica*	†	1·2	159 09	S.10 59
23*	*Suhail*		2·2	223 19	S.43 18
49*	*Vega*		0·1	81 03	N.38 45
39	*Zuben'ubi*	†	2·9	137 45	S.15 54

INTERPOLATION OF G.H.A.

Increment to be added for intervals of G.M.T. to G.H.A. of:
Sun, Aries (♈) and planets ; Moon

SUN, etc.		MOON	SUN, etc.		MOON	SUN, etc.		MOON
m s	° ′	m s	m s	° ′	m s	m s	° ′	m s
00 00		00 00	03 17		03 25	06 37		06 52
	0 00			0 50			1 40	
01		00 02	21		03 29	41		06 56
	0 01			0 51			1 41	
05		00 06	25		03 33	45		07 00
	0 02			0 52			1 42	
09		00 10	29		03 37	49		07 04
	0 03			0 53			1 43	
13		00 14	33		03 41	53		07 08
	0 04			0 54			1 44	
17		00 18	37		03 45	06 57		07 13
	0 05			0 55			1 45	
21		00 22	41		03 49	07 01		07 17
	0 06			0 56			1 46	
25		00 26	45		03 54	05		07 21
	0 07			0 57			1 47	
29		00 31	49		03 58	09		07 25
	0 08			0 58			1 48	
33		00 35	53		04 02	13		07 29
	0 09			0 59			1 49	
37		00 39	03 57		04 06	17		07 33
	0 10			1 00			1 50	
41		00 43	04 01		04 10	21		07 37
	0 11			1 01			1 51	
45		00 47				25		07 42
	0 46							
05		03 12	25		06 39	45		
	0 47			1 37			2 27	
09		03 16	29		06 44	49		
	0 48			1 38			2 28	
13		03 20	33		06 48	53		
	0 49			1 39			2 29	
17		03 25	37		06 52	09 57		
	0 50			1 40			2 30	
03 21		03 29	06 41		06 56	10 00		

* Stars used in H.O. 249 (A.P. 3270) Vol. 1.
† Stars that may be used with Vols. 2 and 3.

Figure 12-11. SHA Obtained from Table

GHA of moon at 1130 GMT	156°02′
GHA Correction for 6 minutes	1°27′
GHA	157°29′
Declination	S 5°52′

Thus at the time of the observation, the subpoint of the moon is at latitude 5°—52′ S, longiture 157°—29′ W.

Finding GHA and Dec of a Star

Since the declination of each star is constant throughout the period of the almanac, it need be shown only once. The GHA of each star changes throughout the day in a similar manner as the GHA of the sun, but with one difference. The sun, moon, and planets move across the sky at varying rates, and as a result, their GHA changes irregularly. However, the stars and the first point of Aries remain fixed in their same relative positions in space, so that the GHA of all stars and Aries changes at the same rate. Consequently, it is unnecessary for the almanac to list the GHA of each navigational star throughout the day. Instead, the almanac lists the GHA of Aries at 10-minute intervals and gives the SHA of the star only once. The GHA of a star for any time can be found by adding the GHA of Aries for that time and the SHA of the star.

The table, "STARS," is found inside the front cover of the almanac and on the back of the star chart. This table lists navigational stars and the following information for each star: the number corresponding to the sky diagram in the back, the name, the magnitude or relative brightness, the SHA, the declination, whether used in H.O. 249, and stars that can be used with declination tables.

On 2 September 1966, Aries is observed at 01^h24^mGMT. What is its GHA and declination? Look at the extracts from the tables in figures 12-10 and 12-11 to see where the values were obtained.

GHA ♈ 01^h20^m GMT	360°—45′
GHA ♈ correction for 4^m	1°—00′
GHA ♈ 01^h24^m	001°—45′
SHA Altair	62°—43′
GHA Altair 01^h24^m	064°—28′
Declination Altair	8°—47′N

Thus at the time of the observation, the subpoint of Altair is at latitude 8°—47′N, longitude 064°—28′W.

NOTE: By use of a table found in H.O. 249 Vol I (Sight Reduction Tables) the GHA of Aries for any time may be found without using the Air Almanac.

CHAPTER 13

Computing Altitude and True Azimuth

This chapter deals with some of the tables used to compute a celestial line of position. Tables containing the required data for resolving the LOP were mentioned several times previously, including the *Air Almanac,* which has already been discussed.

Preceding the mechanics of using the tables, there is a brief explanation of the astronomical triangle upon which the tables are based. This includes a review of the determination of the LHA of Aries and the LHA of a star.

DERIVATION OF LHA AND THE ASTRONOMICAL TRIANGLE

The basic principle of celestial navigation is to consider yourself to be at a certain assumed position at a given time; then by means of the sextant, determine how much your basic assumption is in error. At any given time an observer has a certain relationship to a particular star. He is a certain number of nautical miles away from the subpoint, and the body is at a certain true bearing called azimuth or Zn, measured at his position (see figure 13-1).

Intercept

If the observer assumes himself to be at a given point (called the assumed position) at a given time, there exists at that instant a specific relationship between this assumed position and the subpoint. The various navigational tables provide you with this relationship by solving the astronomical triangle for you. From the navigational tables you can determine how far away your assumed position is from the subpoint and the true bearing (true azimuth or Zn) of the subpoint from the assumed position. This means, in effect, that the tables give you a value called computed altitude (Hc) which would be the correct observed altitude (Ho) if you were anywhere on the circle of equal altitude through the assumed position. Any difference between the computed altitude (Hc) determined for the assumed position and the observed altitude (Ho) as determined by the

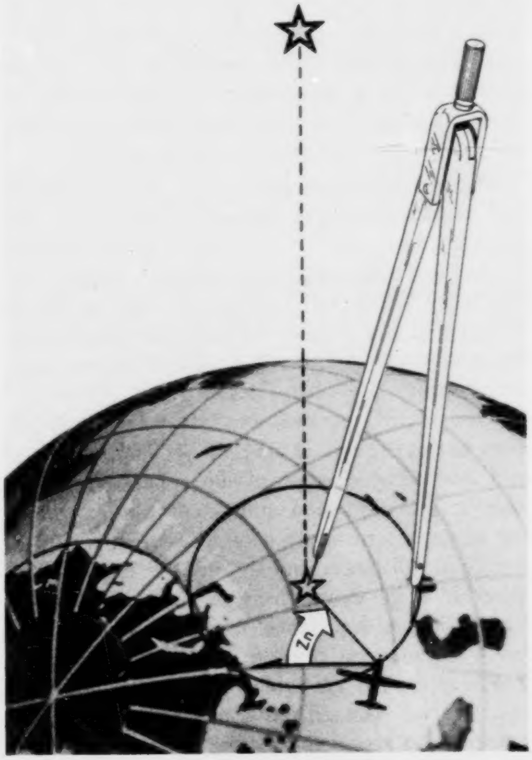


Figure 13-1. Subpoint of a Star

sextant for the actual position is called *intercept*. Intercept is the number of nautical miles between your actual circle of equal altitude and the circle of equal altitude through the assumed position. It is by means of the astronomical triangle that you can solve for Hc and Zn in the astronomical tables.

Construction of the Astronomical Triangle

Consider the solution of a star as it appears on the celestial sphere. Start with the Greenwich meridian and equator. When projected on the celestial sphere they become the Greenwich celestial meridian and the celestial equator (called equinoctial) as shown in figure 13-2. For the given time of the observation, look up the GHA of Aries, and the SHA and declination of the star in the *Air Almanac*, and then position them on the diagram as shown in figure 13-2. Notice also in the same illustration how other known information is derived, namely the LHA of Aries which is equal to the GHA of Aries minus longitude west. You can also see that if the LHA of Aries and SHA of the star are known, the LHA of the star is their sum. Notice that the GHA of Aries plus SHA of the star equals GHA of the star. Also that the GHA of the body minus longitude west (or + longitude east) equals LHA of the body. These are important relationships that are used in the derivation of the Hc and Zn.

Figure 13-3 shows part of the celestial sphere and the astronomical triangle. Notice that the known information of the astronomical triangle is the two sides and the included angle; i.e., Co-Dec, Co-Lat, and LHA★. Co-Dec, or Polar distance, is the angular distance measured along the hour circle of the body from the elevated pole to the body. The side, Co-Lat, is 90° minus the latitude of the assumed position. The included angle in this example is the LHA★. With two sides and the included angle of the spherical triangle known, the third side and the interior angle at the observer are easily solved. The third side is the Zenith distance, and the interior angle at the observer is the Azimuth angle (<Z). Instead of listing the Zenith distance, the astronomical tables list the remaining portion of the 90° from the Zenith or the Hc. Hc equals 90° minus Zenith distance of the assumed position, just as Zenith distance of the assumed position equals 90° − Hc. Note, that when measured with reference to the celestial horizon, Zenith distance is synonymous with co-altitude. Figure 13-4 is a side view of this solution.

So far, the astronomical triangle has been defined only on the celestial sphere. Refer again to figure 13-3 and notice the same triangle on the terrestrial sphere (earth). The same triangle with its corresponding vertices can be defined on the earth as follows: (1) Celestial pole—terrestrial pole; (2) Zenith of assumed position—assumed position; and (3) Star—subpoint of the star. The three interior angles of this triangle are exactly equal to the angles on the celestial sphere. The angular distance of each of the three sides is exactly equal to those on the astronomical triangle. Celestial and terrestrial terms are used interchangeably. For example, refer to figure 13-3 and notice that Co-Lat on the terrestrial triangle is also called Co-Lat on the celestial triangle. To be perfectly correct, the term on the celestial sphere corresponding to latitude on the earth is declination; therefore, the celestial side could well be called, "Co-declination of the Zenith of the assumed position."

Rather than have this confusion, the terrestrial term "Co-Lat" is also used with reference to the celestial sphere, just as latitude of the subpoint is considered to be the declination amount from the equator. Latitude is used when referring to the observer or Zenith, and declination is used when referring to the star or the subpoint. The distance between the subpoint and the assumed position is generally referred to as Zenith distance (Co-Alt) rather than the segment of the vertical circle joining the subpoint and assumed position. These angular distance terms are interchangeable on the celestial and terrestrial spheres.

The values of the Zn (true azimuth) and the interior angle (∠Z) are listed in a special way in H.O. 249 astronomical table. Volume I of H.O. 249 lists the Zn rather than the interior angle. Volumes II and III of H.O. 249 list the interior angle (∠Z) and it is necessary to follow rules printed on each page to convert the interior angle (∠Z) to true azimuth (Zn).

H.O. 249, VOLUME I

Volume I of H.O. 249 deals solely with the solution concerning selected stars and is considered separately from Volumes II and III.

Volume I of H.O. 249 provides complete world coverage from pole to pole for each degree of latitude. The LHA of Aries is listed in 1°

Figure 13-2.
Astronomical Triangle

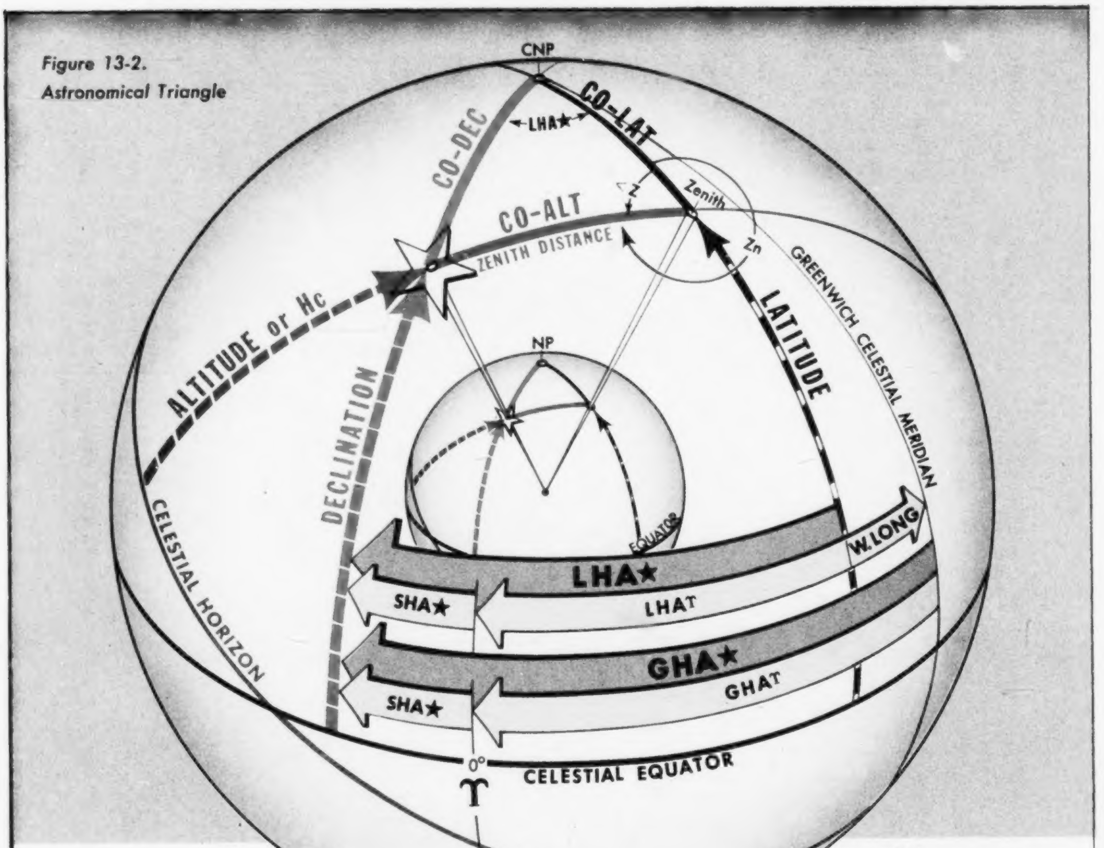
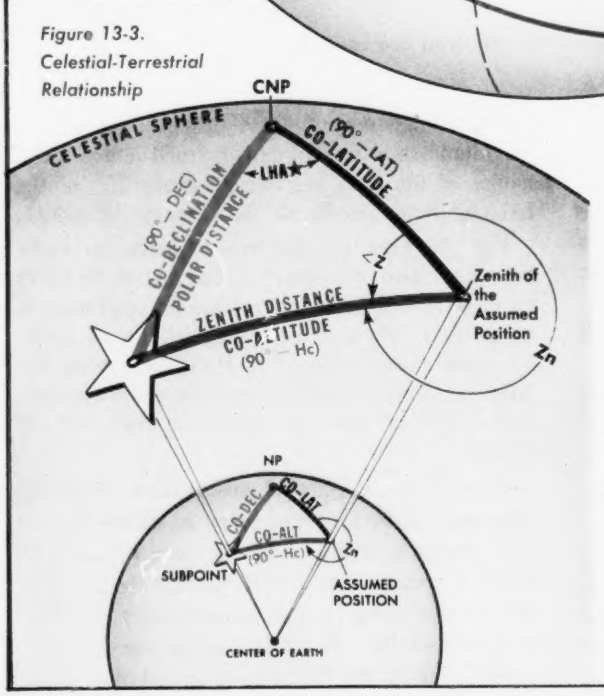

CNP
CO-LAT
LHA★
CO-DEC
Z
Zenith
CO-ALT
ZENITH DISTANCE
Zn
ALTITUDE or Hc
GREENWICH CELESTIAL MERIDIAN
LATITUDE
NP
DECLINATION
CELESTIAL HORIZON
EQUATOR
W.LONG
LHA★
SHA★
LHAϒ
GHA★
SHA★
GHAϒ
0°
ϒ
CELESTIAL EQUATOR

Figure 13-3.
Celestial-Terrestrial
Relationship


CNP
CELESTIAL SPHERE
(90° – LAT)
CO-LATITUDE
LHA★
(90° – DEC)
CO-DECLINATION
POLAR DISTANCE
<Z
Zenith of the Assumed Position
ZENITH DISTANCE
CO-ALTITUDE
(90° – Hc)
Zn
NP
CO-DEC
CO-LAT
CO-ALT
(90°–Hc)
Zn
SUBPOINT
ASSUMED POSITION
CENTER OF EARTH

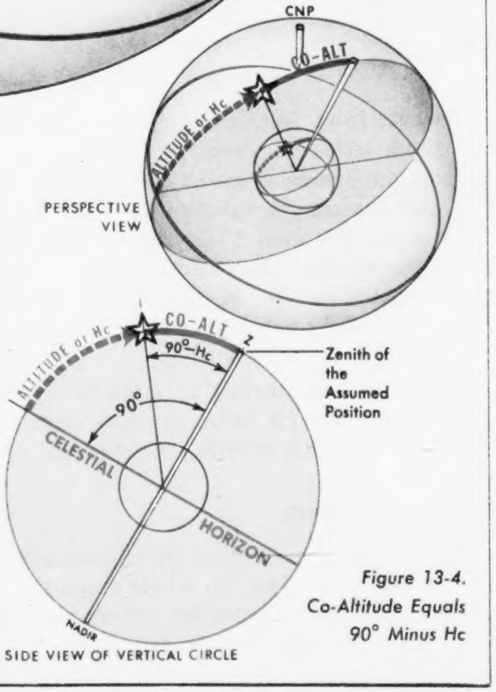
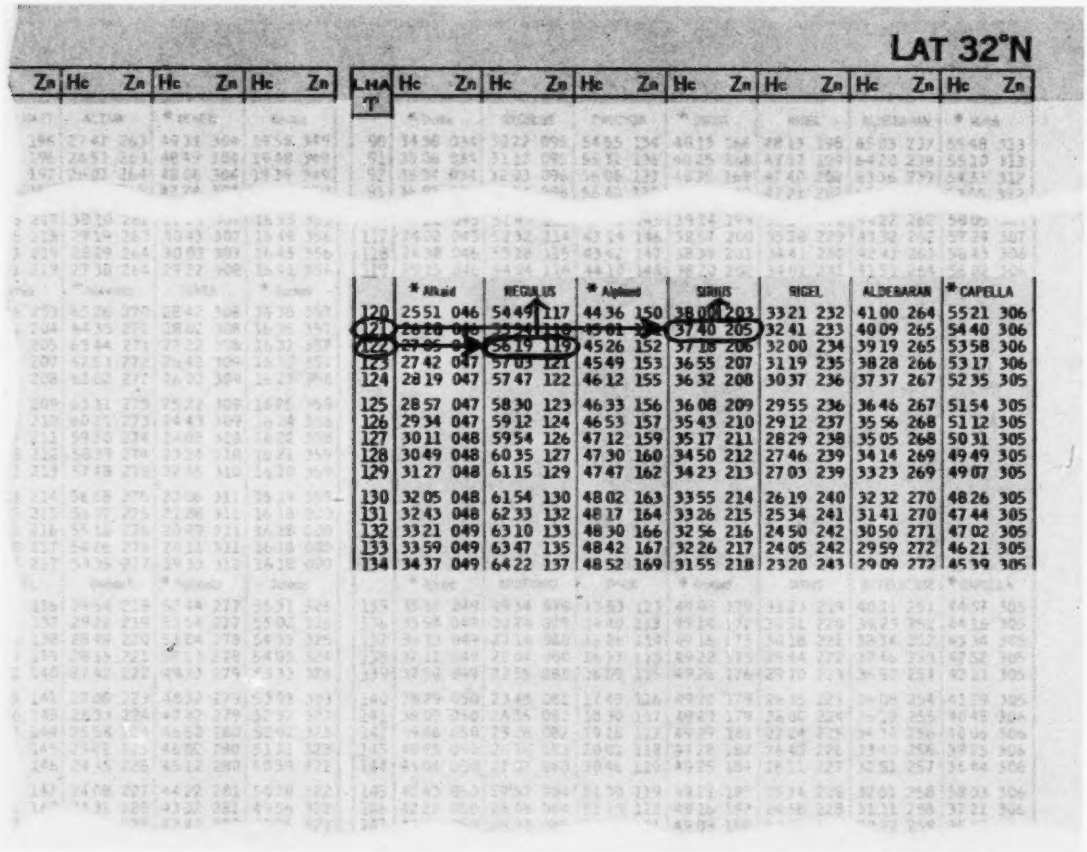

CNP
CO-ALT
ALTITUDE or Hc
PERSPECTIVE VIEW
ALTITUDE or Hc
CO-ALT
Z
90°–Hc
Zenith of the Assumed Position
90°
CELESTIAL
HORIZON
NADIR
SIDE VIEW OF VERTICAL CIRCLE

Figure 13-4.
Co-Altitude Equals
90° Minus Hc



LAT 32°N

LHA ♈	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn
	* Alkaid		REGULUS		* Alphard		SIRIUS		RIGEL		ALDEBARAN		* CAPELLA	
120	25 51	046	54 49	117	44 36	150	38 00	203	33 21	232	41 00	264	55 21	306
121	[illegible]	[illegible]	[illegible]	[illegible]	45 01	[illegible]	37 40	205	32 41	233	40 09	265	54 40	306
122	27 05	[illegible]	56 19	119	45 26	152	37 18	206	32 00	234	39 19	265	53 58	306
123	27 42	047	57 03	121	45 49	153	36 55	207	31 19	235	38 28	266	53 17	306
124	28 19	047	57 47	122	46 12	155	36 32	208	30 37	236	37 37	267	52 35	305
125	28 57	047	58 30	123	46 33	156	36 08	209	29 55	236	36 46	267	51 54	305
126	29 34	047	59 12	124	46 53	157	35 43	210	29 12	237	35 56	268	51 12	305
127	30 11	048	59 54	126	47 12	159	35 17	211	28 29	238	35 05	268	50 31	305
128	30 49	048	60 35	127	47 30	160	34 50	212	27 46	239	34 14	269	49 49	305
129	31 27	048	61 15	129	47 47	162	34 23	213	27 03	239	33 23	269	49 07	305
130	32 05	048	61 54	130	48 02	163	33 55	214	26 19	240	32 32	270	48 26	305
131	32 43	048	62 33	132	48 17	164	33 26	215	25 34	241	31 41	270	47 44	305
132	33 21	049	63 10	133	48 30	166	32 56	216	24 50	242	30 50	271	47 02	305
133	33 59	049	63 47	135	48 42	167	32 26	217	24 05	242	29 59	272	46 21	305
134	34 37	049	64 22	137	48 52	169	31 55	218	23 20	243	29 09	272	45 39	305

Figure 13-5. Enter Tables with LHA Aries and Latitude

increments from latitudes of 0° to 69° North and South inclusive. From 70° through 89° of latitude, the meridians are so close together that it is only necessary to tabulate the values of the LHA of Aries in even 2° increments. There are two pages devoted to each whole degree of latitude between latitudes 69° N and 69° S inclusive. From there to the pole, only one page is devoted to each whole degree of latitude.

The three stars marked by asterisks on each page provide sets for fixing purposes which are favorably situated in altitude and azimuth.

Entering Arguments

The entering arguments are the assumed latitude and the LHA of Aries (to whole degrees). At any one time the navigator has the choice of the listed stars for that latitude and Polaris. The names of the stars are in capital letters if the star is of first magnitude or brighter; the second magnitude stars are printed in small letters. The names of the stars are relisted every 15° of the LHA of Aries (every 30° in the polar latitudes).

For the time the navigator expects to make his observation, commonly called a shot, he looks up the GHA of Aries and applies his approximate longitude to get the approximate LHA of Aries. He then enters Volume I, H.O. 249, with the latitude closest to his DR latitude and the approximate LHA of Aries to select the stars he will shoot.

Since a single celestial observation results in only one LOP, it is necessary to shoot two or more bodies to obtain a fix. Suppose he wants to shoot at approximately 0230 GMT. He looks up the GHA of Aries (in the *Air Almanac*) and finds it to be 196°06′. The DR position for this time is 31°48′ N-75°26′ W. A quick calculation shows that the LHA of Aries is approximately 121°, and the closest latitude is 32° N. Notice in the portion of the tables reproduced in figure 13-5 that the available stars at this position are Alkaid, Regulus, Alphard, Sirius, Rigel, Aldebaran, and Capella. Using Sirius, a shot is taken at 0231 and the Ho obtained is 37°50′.

GHA ♈ for 0230 GMT	196°06′
Corr for 1 minute	+ 15′
GHA ♈ for 0231 GMT	196°21′
Closest long. to DR pos for whole degree LHA	−75°21′ W (assumed long.)
LHA ♈ for 0231 GMT	121°

The closest whole degree of latitude is 32° N; therefore it is used as the assumed latitude. The assumed longitude is selected as the closest point that results in an LHA of Aries that is a whole degree (no minutes). The Hc of Sirius is listed as 37°40′. The Zn is 205°.

The second shot was taken at 0234 GMT on Regulus, the Ho being 55°30′. A new DR position could be obtained for 0234 GMT, but the 0230 DR position will suffice for this determination of Hc and Zn.

GHA ♈ for 0230 GMT	196°06′
Corr for 4 minutes	+ 1°00′
GHA ♈ for 0234	197°06′
Closest long. for whole degree LHA	−75°06′ W (assumed long.)
LHA ♈ for 0234 GMT	122°

The assumed latitude is still 32° N, and in this case 75°06′ is the assumed longitude, since this is the closest longitude to the DR longitude that results in the LHA of Aries being a whole degree. The Hc of Regulus is listed as 56°19′, and the Zn as 119°.

The various corrections that must be applied as well as the plotting of the fix are discussed later.

Summary of Procedure

The steps in this procedure are as follows:

1. Using the *Air Almanac,* determine the GHA of Aries for the time of observation.
2. Assume a position as close as possible to the DR position at the time of the shot so that the latitude and LHA of Aries in whole degrees may be mentally determined.
3. In H.O. 249, turn to the page of the assumed latitude and opposite the LHA of Aries select the stars to be shot. In making the selection, assume that the LHA of Aries will change 1° every 4 minutes of time.
4. Shoot the body and record the time, Ho, and the name of the body.
5. For the time of observation, obtain the GHA of Aries, and apply the assumed longitude to determine the LHA of Aries.
6. Turn to the pages for the assumed latitude and opposite the LHA of Aries in the column headed by the name of the star, find and record the Hc and Zn.

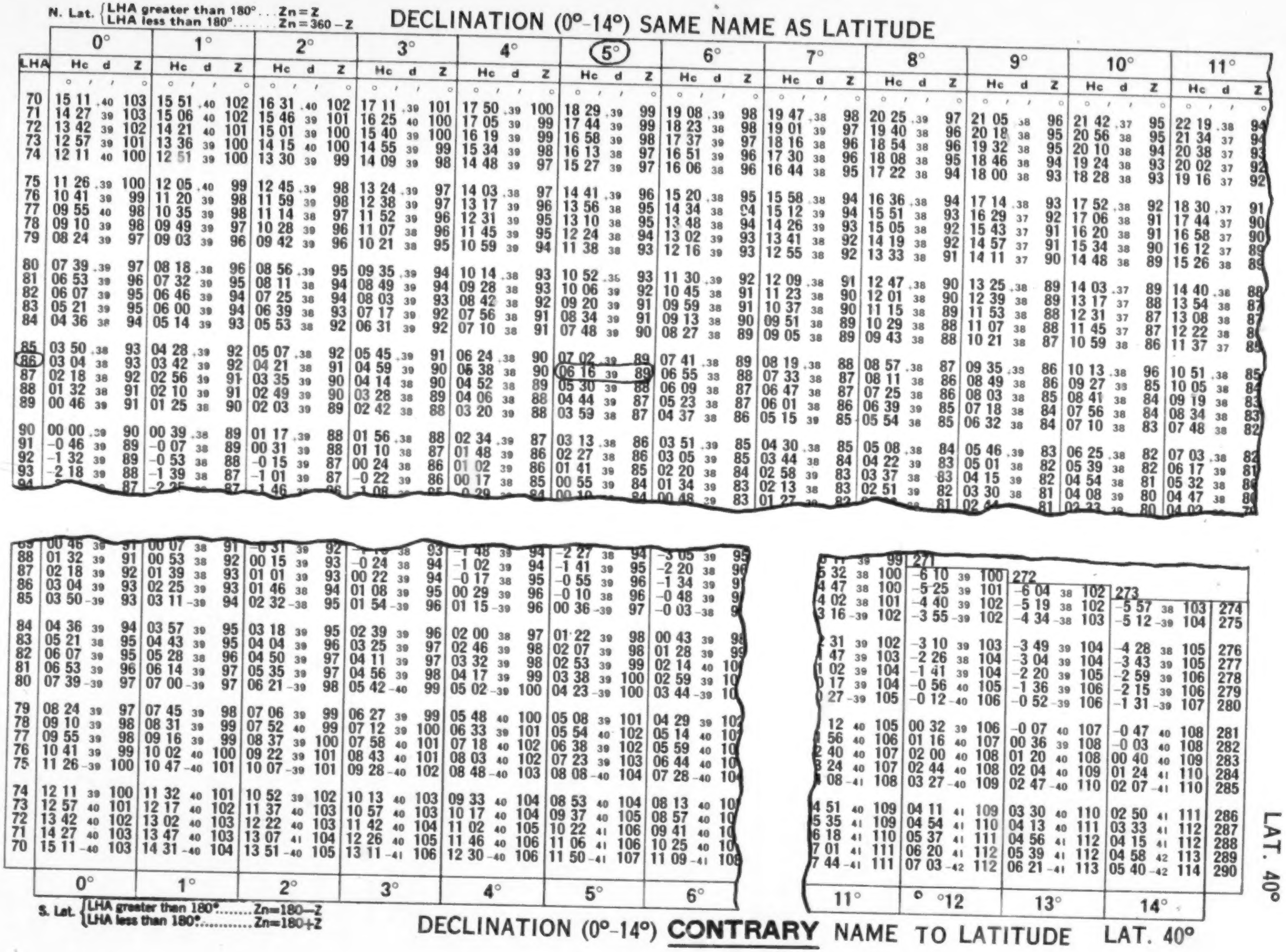
H.O. 249, VOLUMES II AND III

Volume I of H.O. 249 consists of tables of Hc and Zn for selected stars. Since the declination and SHA of each star change slowly, these tables can be used for many years with only small corrections. The declination and SHA of a nonstellar body change rapidly, making a permanent format similar to Volume I impossible for the sun, moon, and planets.

Volumes II and III of H.O. 249 are declination tables adequate for determining the Hc and Zn of any celestial body within the declination range of 30° north to 30° south. They are intended primarily for use when observing nonstellar (solar system) bodies. Volume II provides for latitudes from the equator to 39° North or South, and Volume III provides for latitudes from 40° North or South to the poles. Provision is made for observed altitudes from 90° to 3° below the horizon (7° from latitudes 70° to the pole). In view of refraction and of possible long intercepts, the tables are actually extended 2° below these limits.

Entering Arguments

Volumes II and III are entered with the LHA of the body, in contrast to Volume I, which is entered with the LHA of Aries. The range extends from 0° through all LHAs applicable within the altitude limits of the body. Between



N. Lat. {LHA greater than 180° . . . Zn = Z
{LHA less than 180° . . . . . . Zn = 360 − Z

DECLINATION (0°-14°) SAME NAME AS LATITUDE

LHA	0°			1°			2°			3°			4°			5°			6°			7°			8°			9°			10°			11°		
	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z
	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°
70	15 11	+40	103	15 51	+40	102	16 31	+40	102	17 11	+39	101	17 50	+39	100	18 29	+39	99	19 08	+39	98	19 47	+38	98	20 25	+39	97	21 05	+38	96	21 42	+37	95	22 19	+38	94
71	14 27	39	103	15 06	40	102	15 46	39	101	16 25	40	100	17 05	39	99	17 44	39	99	18 23	38	98	19 01	39	97	19 40	38	96	20 18	38	95	20 56	38	95	21 34	37	94
72	13 42	39	102	14 21	40	101	15 01	39	100	15 40	39	100	16 19	39	99	16 58	39	98	17 37	39	97	18 16	38	96	18 54	38	96	19 32	38	95	20 10	38	94	20 38	37	93
73	12 57	39	101	13 36	39	100	14 15	40	100	14 55	39	99	15 34	39	98	16 13	38	97	16 51	39	96	17 30	38	96	18 08	38	95	18 46	38	94	19 24	38	93	20 02	37	92
74	12 11	40	100	12 51	39	100	13 30	39	99	14 09	39	98	14 48	39	97	15 27	39	97	16 06	38	96	16 44	38	95	17 22	38	94	18 00	38	93	18 28	38	93	19 16	37	92
75	11 26	+39	100	12 05	+40	99	12 45	+39	98	13 24	+39	97	14 03	+38	97	14 41	+39	96	15 20	+38	95	15 58	+38	94	16 36	+38	94	17 14	+38	93	17 52	+38	92	18 30	+37	91
76	10 41	39	99	11 20	39	98	11 59	39	98	12 38	39	97	13 17	39	96	13 56	38	95	14 34	38	94	15 12	39	94	15 51	38	93	16 29	37	92	17 06	38	91	17 44	37	90
77	09 55	40	98	10 35	39	98	11 14	38	97	11 52	39	96	12 31	39	95	13 10	38	95	13 48	38	94	14 26	39	93	15 05	38	92	15 43	37	91	16 20	38	91	16 58	37	90
78	09 10	39	98	09 49	39	97	10 28	39	96	11 07	38	96	11 45	39	95	12 24	38	94	13 02	39	93	13 41	38	92	14 19	38	92	14 57	37	91	15 34	38	90	16 12	37	89
79	08 24	39	97	09 03	39	96	09 42	39	96	10 21	38	95	10 59	39	94	11 38	38	93	12 16	39	93	12 55	38	92	13 33	38	91	14 11	37	90	14 48	38	89	15 26	38	89
80	07 39	+39	97	08 18	+38	96	08 56	+39	95	09 35	+39	94	10 14	+38	93	10 52	+38	93	11 30	+39	92	12 09	+38	91	12 47	+38	90	13 25	+38	89	14 03	+37	89	14 40	+38	88
81	06 53	39	96	07 32	39	95	08 11	38	94	08 49	39	94	09 28	38	93	10 06	39	92	10 45	38	91	11 23	38	90	12 01	38	90	12 39	38	89	13 17	37	88	13 54	38	87
82	06 07	39	95	06 46	39	94	07 25	38	94	08 03	39	93	08 42	38	92	09 20	39	91	09 59	38	91	10 37	38	90	11 15	38	89	11 53	38	88	12 31	37	87	13 08	38	87
83	05 21	39	95	06 00	39	94	06 39	38	93	07 17	39	92	07 56	38	91	08 34	39	91	09 13	38	90	09 51	38	89	10 29	38	88	11 07	38	88	11 45	37	87	12 22	38	86
84	04 36	38	94	05 14	39	93	05 53	38	92	06 31	39	92	07 10	38	91	07 48	39	90	08 27	38	89	09 05	38	89	09 43	38	88	10 21	38	87	10 59	38	86	11 37	37	85
85	03 50	+38	93	04 28	+39	92	05 07	+38	92	05 45	+39	91	06 24	+38	90	07 02	+39	89	07 41	+38	89	08 19	+38	88	08 57	+38	87	09 35	+39	86	10 13	+38	96	10 51	+38	85
86	03 04	38	93	03 42	39	92	04 21	38	91	04 59	39	90	05 38	38	90	06 16	39	89	06 55	38	88	07 33	38	87	08 11	38	86	08 49	38	86	09 27	38	85	10 05	38	84
87	02 18	38	92	02 56	39	91	03 35	39	90	04 14	38	90	04 52	38	89	05 30	39	88	06 09	38	87	06 47	38	87	07 25	38	86	08 03	38	85	08 41	38	84	09 19	38	83
88	01 32	38	91	02 10	39	91	02 49	39	90	03 28	38	89	04 06	38	88	04 44	39	87	05 23	38	87	06 01	38	86	06 39	39	85	07 18	38	84	07 56	38	84	08 34	38	83
89	00 46	39	91	01 25	38	90	02 03	39	89	02 42	38	88	03 20	39	88	03 59	38	87	04 37	38	86	05 15	39	85	05 54	38	85	06 32	38	84	07 10	38	83	07 48	38	82
90	00 00	+39	90	00 39	+38	89	01 17	+39	88	01 56	+38	88	02 34	+39	87	03 13	+38	86	03 51	+39	85	04 30	+38	85	05 08	+38	84	05 46	+39	83	06 25	+38	82	07 03	+38	82
91	−0 46	39	89	−0 07	38	89	00 31	39	88	01 10	38	87	01 48	39	86	02 27	38	86	03 05	39	85	03 44	38	84	04 22	39	83	05 01	38	82	05 39	38	82	06 17	39	81
92	−1 32	39	89	−0 53	38	88	−0 15	39	87	00 24	38	86	01 02	39	86	01 41	39	85	02 20	38	84	02 58	39	83	03 37	38	83	04 15	39	82	04 54	38	81	05 32	38	80
93	−2 18	39	88	−1 39	38	87	−1 01	39	87	−0 22	39	86	00 17	38	85	00 55	39	84	01 34	39	83	02 13	38	83	02 51	39	82	03 30	38	81	04 08	39	80	04 47	38	80
94	[illegible]	[illegible]	87	−2 25	[illegible]	87	−1 46	[illegible]	86	−1 08	[illegible]	85	−0 29	[illegible]	84	00 10	[illegible]	84	00 48	39	83	01 27	[illegible]	82	[illegible]	[illegible]	81	02 44	[illegible]	81	[illegible]	[illegible]	80	04 02	[illegible]	79

LHA	0°			1°			2°			3°			4°			5°			6°		
89	00 46	39	91	00 07	38	91	−0 31	39	92	[illegible]	38	93	−1 48	39	94	−2 27	38	94	−3 05	39	95
88	01 32	39	91	00 53	38	92	00 15	39	93	−0 24	38	94	−1 02	39	94	−1 41	39	95	−2 20	38	96
87	02 18	39	92	01 39	38	93	01 01	39	93	00 22	39	94	−0 17	38	95	−0 55	39	96	−1 34	39	9
86	03 04	39	93	02 25	39	93	01 46	38	94	01 08	39	95	00 29	39	96	−0 10	38	96	−0 48	39	9
85	03 50	−39	93	03 11	−39	94	02 32	−38	95	01 54	−39	96	01 15	−39	96	00 36	−39	97	−0 03	−38	9
84	04 36	39	94	03 57	39	95	03 18	39	95	02 39	39	96	02 00	38	97	01 22	39	98	00 43	39	9
83	05 21	38	95	04 43	39	95	04 04	39	96	03 25	39	97	02 46	39	98	02 07	39	98	01 28	39	9
82	06 07	39	95	05 28	38	96	04 50	39	97	04 11	39	97	03 32	39	98	02 53	39	99	02 14	40	10
81	06 53	39	96	06 14	39	97	05 35	39	97	04 56	39	98	04 17	39	99	03 38	39	100	02 59	39	10
80	07 39	−39	97	07 00	−39	97	06 21	−39	98	05 42	−40	99	05 02	−39	100	04 23	−39	100	03 44	−39	10
79	08 24	39	97	07 45	39	98	07 06	39	99	06 27	39	99	05 48	40	100	05 08	39	101	04 29	39	10
78	09 10	39	98	08 31	39	99	07 52	40	99	07 12	39	100	06 33	39	101	05 54	40	102	05 14	40	10
77	09 55	39	98	09 16	39	99	08 37	39	100	07 58	40	101	07 18	40	102	06 38	39	102	05 59	40	10
76	10 41	39	99	10 02	40	100	09 22	39	101	08 43	40	101	08 03	40	102	07 23	39	103	06 44	40	10
75	11 26	−39	100	10 47	−40	101	10 07	−39	101	09 28	−40	102	08 48	−40	103	08 08	−40	104	07 28	−40	10
74	12 11	39	100	11 32	40	101	10 52	39	102	10 13	40	103	09 33	40	104	08 53	40	104	08 13	40	10
73	12 57	40	101	12 17	40	102	11 37	40	103	10 57	40	103	10 17	40	104	09 37	40	105	08 57	40	10
72	13 42	40	102	13 02	40	103	12 22	40	103	11 42	40	104	11 02	40	105	10 22	41	106	09 41	40	10
71	14 27	40	103	13 47	40	103	13 07	41	104	12 26	40	105	11 46	40	106	11 06	41	106	10 25	40	10
70	15 11	−40	103	14 31	−40	104	13 51	−40	105	13 11	−41	106	12 30	−40	106	11 50	−41	107	11 09	−41	108
	0°			1°			2°			3°			4°			5°			6°		

11°			°12			13°			14°			LHA
11	39	99										271
5 32	38	100	−6 10	39	100							272
4 47	38	100	−5 25	39	101	−6 04	38	102				273
4 02	38	101	−4 40	39	102	−5 19	38	102	−5 57	38	103	274
3 16	−39	102	−3 55	−39	102	−4 34	−38	103	−5 12	−39	104	275
31	39	102	−3 10	39	103	−3 49	39	104	−4 28	38	105	276
47	39	103	−2 26	38	104	−3 04	39	104	−3 43	39	105	277
1 02	39	104	−1 41	39	104	−2 20	39	105	−2 59	39	106	278
17	39	104	−0 56	40	105	−1 36	39	106	−2 15	39	106	279
27	−39	105	−0 12	−40	106	−0 52	−39	106	−1 31	−39	107	280
12	40	105	00 32	39	106	−0 07	40	107	−0 47	40	108	281
56	40	106	01 16	40	107	00 36	39	108	−0 03	40	108	282
2 40	40	107	02 00	40	108	01 20	40	108	00 40	40	109	283
3 24	40	107	02 44	40	108	02 04	40	109	01 24	41	110	284
08	−41	108	03 27	−40	109	02 47	−40	110	02 07	−41	110	285
4 51	40	109	04 11	41	109	03 30	40	110	02 50	41	111	286
5 35	41	109	04 54	41	110	04 13	40	111	03 33	41	112	287
6 18	41	110	05 37	41	111	04 56	41	112	04 15	41	112	288
7 01	41	111	06 20	41	112	05 39	41	112	04 58	42	113	289
7 44	−41	111	07 03	−42	112	06 21	−41	113	05 40	−42	114	290
11°			°12			13°			14°			

LAT. 40°

S. Lat. {LHA greater than 180°.........Zn=180−Z
{LHA less than 180°............Zn=180+Z

DECLINATION (0°-14°) **CONTRARY** NAME TO LATITUDE LAT. 40°

Figure 13-6. Enter Table with Latitude, Declination, and LHA

latitude 70° and the pole, the LHA interval is 2°; for latitudes below 70°, the interval is 1°. Arguments of LHA of the body less than 180° appear on the left margin, and arguments greater than 180° appear on the right.

Several pages are devoted to each degree of latitude. Each page has 15 declination columns and is labeled with its value at the top and bottom. Each page is also marked *Declination Contrary Name To Latitude,* or *Declination Same Name As Latitude*. If the body being used has a southern declination and the assumed position is in north latitudes, use the page headed *Declination Contrary Name To Latitude*. Conversely, if the declination of the body and the latitude of the assumed position are of the same name, the page headed, *Declination Same Name As Latitude* is used.

The entering arguments of LHA of the body, for declination of contrary name to latitude, always increase from the bottom of the page on the left side, and decrease on the right. The opposite arrangement exists on pages where declination and latitude have the same name. Occasionally, one page will be blank in the middle and the top half will cover *Declination Same Name As Latitude;* while the bottom half will be *Declination Contrary Name to Latitude.*

Azimuth angle (Z) is listed instead of true azimuth (Zn), as in Volume I. Since true azimuth is used for plotting, it is necessary to convert azimuth angle to true azimuth. The rules for conversion are listed on the left-hand side at the top and bottom of every page as shown.

Besides the listing of Hc and Z in Volumes II and III of H.O. 249, there is also recorded a value of "d." This d-value is the change in altitude (Hc) with a 1° increase in declination. If the LHA and declination of the body and the latitude of the assumed position are each a whole number of degrees, the Hc and Z are found in the correct declination column opposite the LHA of the body on the page marked by the proper latitude value.

For example, refer to the portion of the table shown in figure 13-6. At a latitude of 40° N, if the LHA of a body is 86° and its declination is N 5°, the Hc is 06°16′ and the azimuth angle (Z) is 089°. The rule in the upper left-hand corner of the page applies for the conversion of Z to Zn. Zn = (360° − Z) or (360° − 089°) = 271°. Here again the position is assumed so that latitude and LHA are whole numbers.

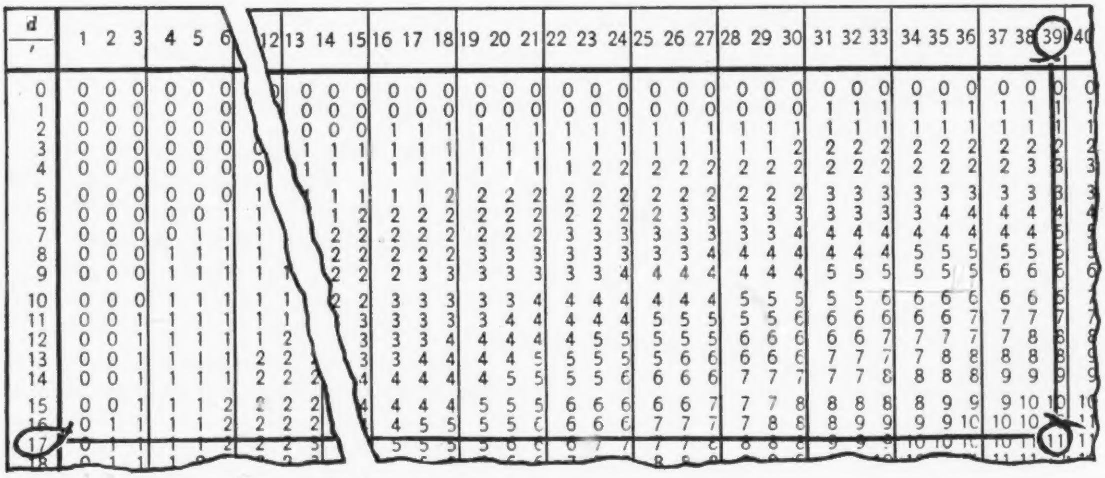
Interpolation for Declination

When the declination of a body is a number of minutes in addition to a whole number of degrees, the altitude (Hc) is extracted for the whole number of degrees and corrected by interpolation for the additional minutes. There is rarely a need for interpolation of azimuth angle (Z), which is given only to the nearest degree.

Interpolation for Hc should always be made in the direction of increasing declination, in accordance with the sign of the d-value. Not all of the signs are printed; the sign is given at least once in each block of five entries, and can always be found by looking either up or down the column from the value of "d" in question. The correction to altitude for additional minutes of declination is proportional to "d" and proportional to the number of additional minutes.

In the previous example the latitude was 40° N, the LHA of the body was 86°, and the declination was N 5°. Suppose the declination had been N 5°17′. The basic figures obtained would be 06°16′ Hc and 089° Z as before, and the true azimuth would still be 271°. The Hc of 06°16′ is not correct for a declination of N 5°17′, but is correct for N 5°. The Hc change for an additional one degree of declination is +39 minutes of declination. However, the correction needed in this case is for 17 minutes, not a whole degree. Consequently, the additional correction is 17/60 of +39′. To the closest whole number, this would be a +11 minutes.

This multiplication can be done on the slide rule face of the DR computer, or by means of a table found in the back of Volumes II and III, H.O. 249. A portion of this table is shown in Figure 13-7. Notice that there are no signs listed. The proper sign for the answer from this table is the same sign as the basic d-factor. Values of "d" are given across the top of the table, and additional minutes of declination are given down the side of the table. This is Table 5 in H.O. 249, Volumes II and III. In the table the correction, 11′, is found by looking across 17′ for declination and down 39′ for "d", to their intersection at 11′. Since the sign of the d-factor is plus, this correction is added to the tabulated Hc.



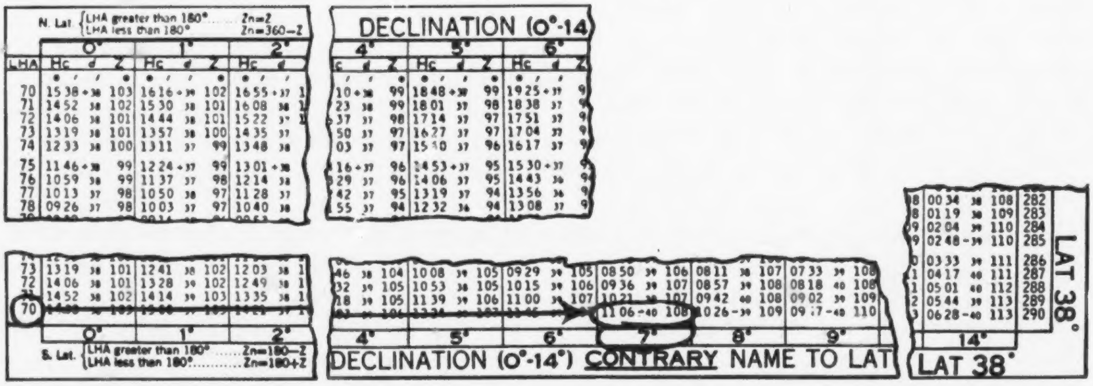
d / ′	1	2	3	4	5	6				12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
0	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
2	0	0	0	0	0	0					0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	0	0	0	0	0	0	0				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2
4	0	0	0	0	0	0	0				1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3
5	0	0	0	0	0	0	1				1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3
6	0	0	0	0	0	1	1					1	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4
7	0	0	0	0	1	1	1					2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	5	5
8	0	0	0	1	1	1	1					2	2	2	2	2	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	5	5	5	5	5	5	5
9	0	0	0	1	1	1	1	1				2	2	2	3	3	3	3	3	3	3	4	4	4	4	4	4	4	5	5	5	5	5	5	6	6	6	6
10	0	0	0	1	1	1	1	1				2	2	3	3	3	3	3	4	4	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6	6	6	7
11	0	0	1	1	1	1	1	1					3	3	3	3	3	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6	6	7	7	7	7	7
12	0	0	1	1	1	1	1	2					3	3	3	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6	7	7	7	7	7	8	8	8
13	0	0	1	1	1	1	2	2					3	3	4	4	4	4	5	5	5	5	5	6	6	6	6	6	7	7	7	7	8	8	8	8	8	9
14	0	0	1	1	1	1	2	2	2				4	4	4	4	4	5	5	5	5	6	6	6	6	7	7	7	7	7	8	8	8	8	9	9	9	9
15	0	0	1	1	1	2	2	2	2				4	4	4	4	5	5	5	6	6	6	6	6	7	7	7	8	8	8	8	8	9	9	9	10	10	10
16	0	1	1	1	1	2	2	2	2					4	5	5	5	5	6	6	6	6	7	7	7	7	8	8	8	9	9	9	9	10	10	10	[illegible]	11
17	0	1	1	1	1	2	2	2	3					5	5	5	5	6	6	6	7	7	7	7	8	8	8	8	9	9	9	10	10	10	10	11	11	11

Figure 13-7. Table Performs the Multiplication

The proper Hc value then becomes 06°16′ + 11′ or 06°27′.

Following is a sample problem showing the solution. Refer to the portion of the tables illustrated in figure 13-8 for the solution. Suppose the sun is observed on 1 March at 1005 GMT. The DR position is 38°12′ N—101°47′ E, and the Ho of the sun is 10°52′.

1005 Declination	S7°37′
1000 GHA	326°53′
Corr for 5 min.	+ 1°15′
1005 GHA	328°08′
Assumed longitude	+101°52′ E
	430°00′
	−360°
1005 LHA	70°
Tab. Hc extracted from tables	11°06′
d-factor extracted from tables	—40
Z extracted from book	108°
d-correction from Table 5 (opposite 37′ and "d" 40)	—25′
Hc	10°41′
Zn (Use the rule at the top left corner of the page)	252°



N. Lat. {LHA greater than 180°........Zn=Z / LHA less than 180°........Zn=360−Z

	0°			1°			2°		
LHA	Hc	d	Z	Hc	d	Z	Hc	d	
	° ′	′	°	° ′	′	°	° ′	′	
70	15 38	+38	103	16 16	+39	102	16 55	+37	1
71	14 52	38	102	15 30	38	101	16 08	38	1
72	14 06	38	101	14 44	38	101	15 22	37	1
73	13 19	38	101	13 57	38	100	14 35	37	
74	12 33	38	100	13 11	37	99	13 48	38	
75	11 46	+38	99	12 24	+37	99	13 01	+38	
76	10 59	38	99	11 37	37	98	12 14	38	
77	10 13	37	98	10 50	38	97	11 28	37	
78	09 26	37	98	10 03	37	97	10 40	38	

DECLINATION (0°-14

4°			5°			6°		
c	d	Z	Hc	d	Z	Hc	d	Z
′	′	°	° ′	′	°	° ′	′	
10	+38	99	18 48	+38	99	19 25	+37	9
23	38	99	18 01	37	98	18 38	37	9
37	37	98	17 14	37	97	17 51	37	9
50	37	97	16 27	37	97	17 04	37	9
03	37	97	15 40	37	96	16 17	37	9
16	+37	96	14 53	+37	95	15 30	+37	9
29	37	96	14 06	37	95	14 43	36	9
42	37	95	13 19	37	94	13 56	36	9
55	37	94	12 32	36	94	13 08	37	9

73	13 19	38	101	12 41	38	102	12 03	38	1
72	14 06	38	101	13 28	39	102	12 49	38	1
	14 52	38	102	14 14	39	103	13 35	38	1
70									
	0°			1°			2°		

S. Lat. {LHA greater than 180°........Zn=180−Z / LHA less than 180°..........Zn=180+Z

46	38	104	10 08	39	105	09 29	39	105	08 50	39	106	08 11	38	107	07 33	39	108
32	39	105	10 53	38	105	10 15	39	106	09 36	39	107	08 57	39	108	08 18	40	108
18	39	105	11 39	39	106	11 00	39	107	10 21	39	107	09 42	40	108	09 02	39	109
									11 06	−40	108	10 26	−39	109	[illegible]	−40	110
4°			5°			6°			7°			8°			9°		

DECLINATION (0°-14°) CONTRARY NAME TO LAT

14°			
00 34	38	108	282
01 19	38	109	283
02 04	39	110	284
02 48	−39	110	285
03 33	39	111	286
04 17	40	111	287
05 01	40	112	288
05 44	39	113	289
06 28	−40	113	290

LAT 38°

LAT 38°

Figure 13-8. Declination (0°-14°) Contrary Name to Latitude

Summary of Procedure

Before proceeding, review the procedure for finding the altitude (Hc) and true azimuth (Zn) of a body whose declination lies between N 30° and S 30°, using Volume II or III of H.O. 249.

1. Shoot the body and record the time of observation, the body's name, and the Ho.
2. From the almanac ascertain the declination and GHA of the body for the time of the observation.
3. Assume a position as close as possible to the DR position so that the latitude is a whole number of degrees, and the longitude combined with the GHA of the body gives a whole number of degrees of LHA of the body. Find the LHA of the body for this position.
4. According to the assumed latitude, select the correct volume (II or III) and page which contains the correct arguments of declination and LHA of the body, temporarily disregarding the odd additional minutes of declination. Thus, if the declination were N 19°55′ use the column for N 19°. Select the table labeled *Declination Same Name as Latitude,* if declination and latitude are both north or both south, or the table labeled *Declination Contrary Name to Latitude,* if one is north and the other south. Opposite the LHA of the body read the tabulated altitude and azimuth angle in the column headed by the whole degrees of the declination.
5. If the declination is not a whole number of degrees, determine the altitude correction for the additional minutes of declination. Enter Table 5 with the value "d" and the number of additional minutes of declination. Apply the correction to the tabulated altitude according to the sign of "d". This is the Hc.
6. Convert azimuth angle (Z) to true azimuth (Zn) by means of the rule at the top or bottom of the page.

This completes the solution for the declination tables. However, there is another point that must be discussed in regard to the solution in Volume I of H.O. 249 for the stars.

PRECESSION AND NUTATION

The earth's axis does not maintain a fixed direction in space. Actually, the earth is like a slow running gyro that is wobbling. There are several separate patterns that the wobble makes. Some of those patterns have short cycles, while others take hundreds of years to complete. Two of the many patterns are shown in figure 13-9. One involves small nodding motions while at the same time completing a larger circular path.

The navigator uses a correction called "precession and nutation" to account for these variations in the apparent position of the stars. This correction is applied only to celestial LOPs determined with H.O. 249, Volume I.

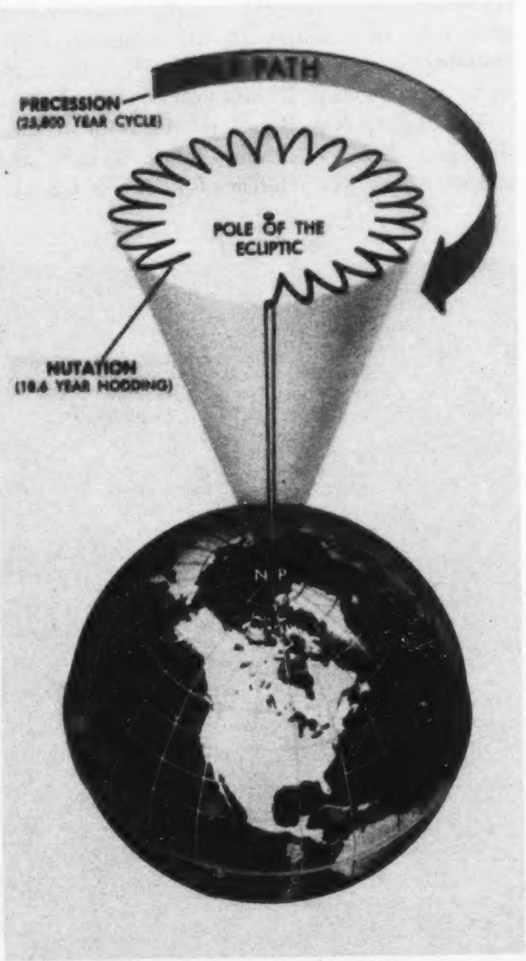


Figure 13-9. Wobble of Earth's Axis Takes Several Patterns

Precession

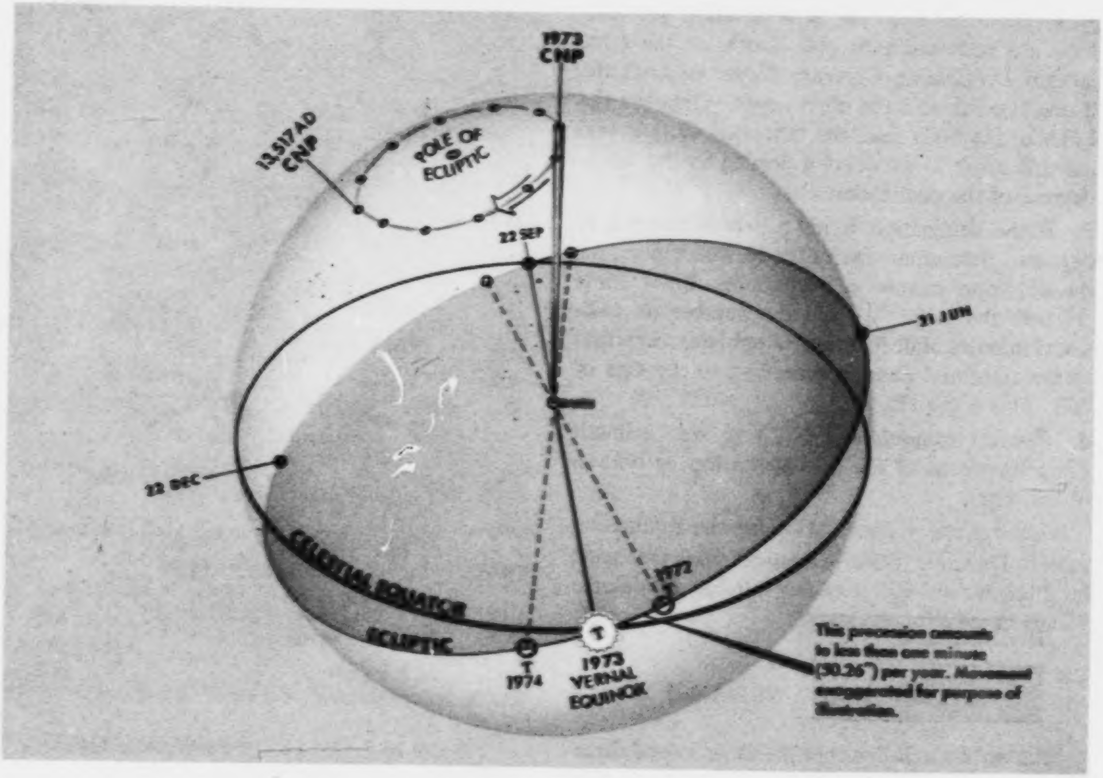
Because of the equatorial bulge, the attractive forces of other solar system bodies, principally the moon, are unbalanced about the center of the earth. The imbalance is directed toward aligning the equator with the plane of the ecliptic. However, the rotation of the earth transforms this force into an effect acting 90° away in the direction of rotation—a precessional effect. As shown in figure 13-10, the result is that the poles describe a conical path westward about the ecliptic poles (the point 90° from the ecliptic). Consequently, the points of intersection of the equator with the ecliptic, or the equinoxes, travel in a westerly direction along the ecliptic. This travel is called *precession of the equinoxes,* and it amounts to approximately five-sixth (⅚) of a minute (50.26″) annually. The equinoxes complete one revolution along the ecliptic in approximately 25,800 years.

The equator is used as a reference for declination and the intersection of the equator and ecliptic is used as a reference for SHA of the star. The movement of these references due to precession of the equinoxes causes slight changes in the celestial coordinates of the stars, which otherwise appear fixed in space. The change usually, but not always, involves a change in declination and a decrease in SHA. A point located at either pole of the ecliptic, however, always has the same celestial coordinates.

Nutation

As the relative positions and distances from the earth to the sun, moon, and planets vary, so does the rate of precession. The only variation of importance in navigation is nutation. "Nutation" from the Latin "te ned" is a "nodding" of the poles, one oscillation occurring in about 18.6 years.

In figure 13-11 you can see that, if the stars remain fixed and the equinoctial moves up and down, the declination of these bodies is changing. Nutation, being approximately perpendicular to the ecliptic, has a negligible effect on SHA, but it



This precession amounts to less than one minute (50.26″) per year. Movement exaggerated for purpose of illustration.

Figure 13-10. Precession of the Equinoxes

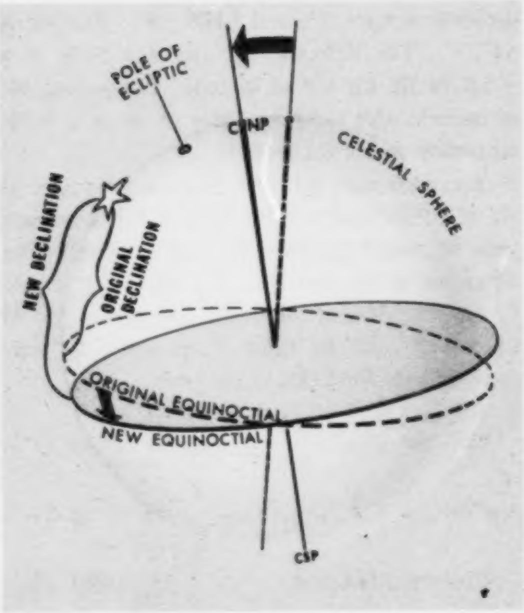


Figure 13-11. Nutation Changes the Declination

does appreciably influence declination. It is caused by complex gravitational forces among the sun, moon, and earth, because of the fact that the moon's orbit does not always lie in the plane of the ecliptic. The change of declination of the celestial bodies caused by the resulting wobble of the earth's axis is called *nutation*.

Position Corrections

Because of precession and nutation, Hc and Zn for a star are accurate only at the instant, or epoch, at which the SHA and declination for the computations are correct. A position obtained at any other time with that Hc and Zn requires a correction. H.O. 249, Volume I, contains Hc's and Zn's calculated for an epoch year (midnight, 1 January, of that year) so if the Volume is used in any other year the resultant position must be corrected. The precession and nutation corrections are combined and given in Table 5 of H.O. 249, Volume I.

Entering arguments for the table are year, latitude, and LHA of Aries, and the correction is presented in the form of a distance and direction to move the fix. The tabulated values show the distance, parallel to the ecliptic, between the observer's position in the year of the fix and the position in 1965 at the latitude and LHA of Aries.

Directions for using Table 5 are printed in the introduction of H.O. 249, Volume 1. Only one point needs emphasis here: the table is to be used only for observations plotted with the aid of H.O. 249, Volume I—never in conjunction with Volume II or III.

TRIPLE INTERPOLATION

Ordinarily, when the navigator uses celestial tables, he assumes a position such that the latitude and LHA are whole degrees. With such a procedure, interpolation for LHA and latitude is unnecessary. Sometimes, however, the altitude (Hc) and true azimuth (Zn) of a body may be needed for some definite position. Then he must interpolate for latitude and LHA as well as for declination. This process is called *triple interpolation.*

In interpolation, first find the tabulated altitude (Hc) and true azimuth (Zn) for the lower whole number of degrees of latitude and LHA and declination in the case of Volumes II and III of H.O. 249. Correct this tabulated altitude (Hc) not only for declination, but also for additional minutes of LHA and latitude. These corrections, added algebraically to the tabulated altitude (Hc), give the correct Hc for the given position. The true azimuth originally obtained is used, without correction, as the correct true azimuth (Zn) of the body for the exact position.

H.O. 249, Volumes II and III

Triple interpolation, using the declination tables of H.O. 249, involves the regular correction for declination solved in the same manner as a regular solution. In addition, there are corrections that must be made for odd minutes of latitude and LHA of the body.

LATITUDE CORRECTION. The correction for latitude is made in this manner:

1. Using the same basic declination and LHA (whole degrees), obtain the Hc for the next higher whole degree of latitude. Compare the new Hc with the old one. This is the correction for 60 minutes of latitude. For example, if a correction for 13 minutes of latitude is required, find 13/60 of the difference of the two Hc's.

2. Using Table 5 obtain the correction to the original Hc for odd minutes of latitude. This table is designed to solve this multiplication for declination, but it will also work for latitude and LHA. The correction has a plus sign if the Hc for the next higher latitude is greater, and a minus sign if it is smaller.

LHA CORRECTION. The correction of LHA is accomplished in the same manner as the latitude correction, except that the next higher LHA is read. The procedure is as follows:

1. Using the same basic declination and latitude (whole degrees), obtain the Hc for the next higher whole degree of LHA. Compare the new Hc with the old one. This is the correction for 60 minutes of LHA. For example, if a correction of 42 minutes of LHA is required, find 42/60 of the difference of the two Hc's just obtained.

2. Again, Table 5 solves the multiplication for fractional parts of 60, hence will work for LHA, latitude, and declination.

3. Using Table 5, obtain the correction to the original Hc for the odd minutes of LHA of the body. The correction has a plus sign if the Hc for the next higher LHA is greater, and a minus sign if it is smaller.

SAMPLE PROBLEM. The corrections for declination, latitude, and LHA are added to the original Hc algebraically. This new Hc is the correct Hc for the exact position, rather than for some assumed position. A sample problem follows:

The position is 41°44′ N, 121°32′ W, and the sun is the body. The date is April 1966 and the time is 2110 GMT.

Declination	N 9°33′
2110 GHA Sun	137°27′
Longitude	−121°32′W
2110 LHA Sun	15°55′

The basic LHA is 15°, declination is same 9°, and latitude is 41°. Taken from the tables, in figure 13-12, the original Hc is 55°21′, "d" is +56°, and Z is 153°.

1. Correction for declination compares a "d" of +56 and 33 odd minutes of declination. Table 5 gives the correction as +31′.

2. The correction for latitude compares the original Hc of 55°21′ and the Hc for 42° N, declination same 9°, and LHA 15°. This Hc is 54°27′. The difference of the two Hc's is a −54′ of Hc for 60′ of latitude. Comparing 44′ of latitude with −54′ in Table 5 gives a −40′ correction to Hc for latitude.

3. The correction for LHA compares the original Hc of 55°21′ and the Hc for 41° N, declination same 9°, and LHA 16°. This Hc is 55°00′. The difference of the two Hc's is a minus 21′ of Hc for 60′ of LHA of the body. Comparing 55′ of LHA with −21′ in Table 5 gives a −19′ correction to Hc for LHA of the body.

4. Original Hc	55°21′	
Corr for Dec	+ 31′	(Step 1)
	55°52′	
Corr for Lat	− 40′	(Step 2)
	55°12′	
Corr for LHA body	− 19′	(Step 3)
Final correct Hc for given position, date, and time.	54°53′	

Z = 153°; Zn = 360°−Z (position in N lat and LHA less than 180°); hence, Zn = 360° − 153° or 207°.

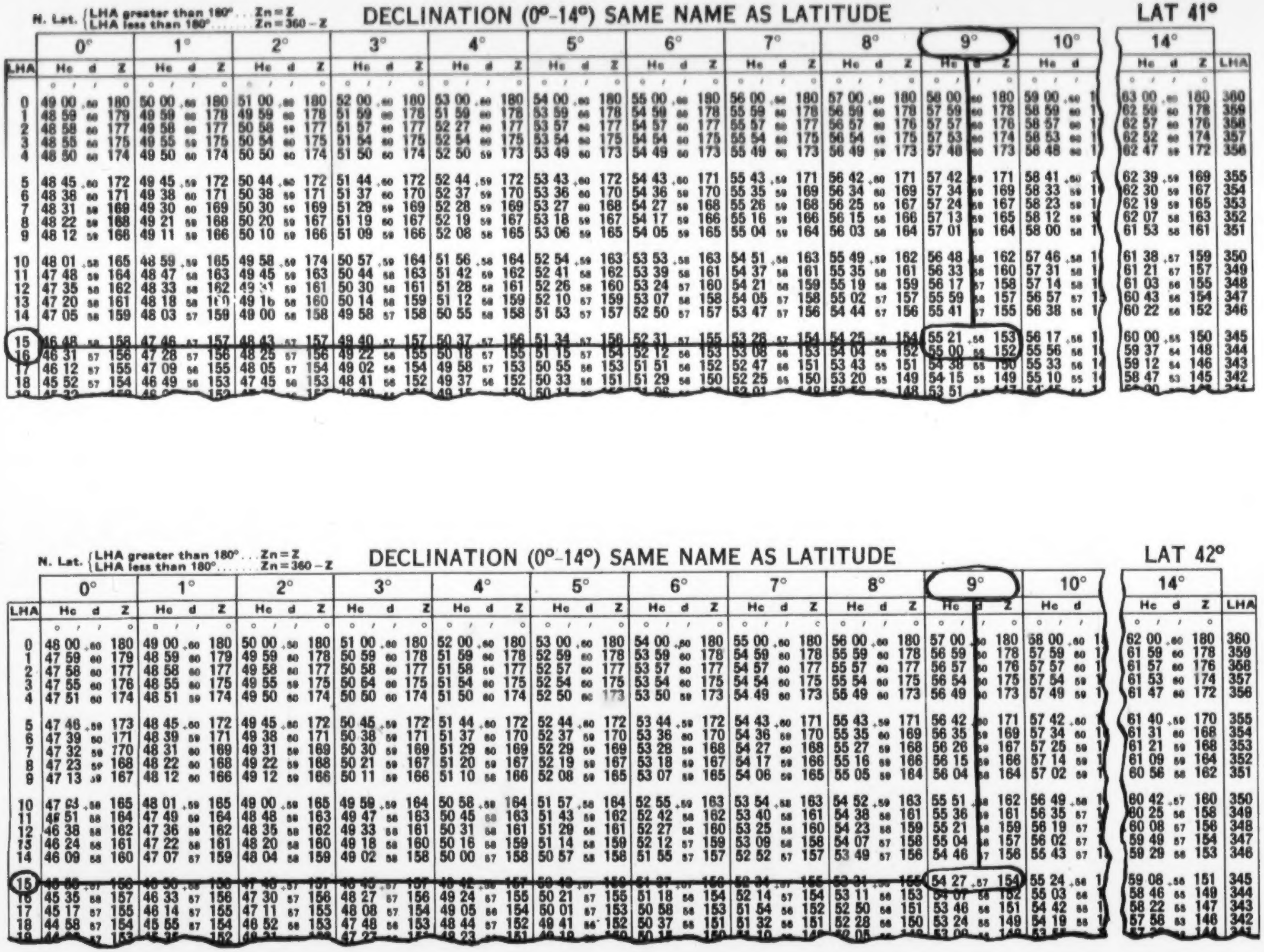
H.O. 249, Volume I

When triple interpolating for the Hc and Zn of a specific point, using the star tables, the corrections for latitude and LHA are handled just as in the procedure for the declination tables.

CORRECTIONS. Therefore, the steps in their respective order are:

1. Obtain the precession/nutation correction from Table V in the back of the book and apply this correction in reverse to the original position. This gives the new position which is then interpolated for LHA and latitude. The resultant Hc and Zn will be correct, however, for the original given position.

2. The correction for latitude compares the original Hc with the Hc for 1° of latitude higher (same LHA) to give the Hc correction for 60′ of latitude. Use this difference of Hc values and the odd number of minutes of latitude to obtain the latitude correction. If Table 5 of Volume II or III is available, use this for the correction. If not, multiply the fraction *odd minutes of latitude*



N. Lat. {LHA greater than 180° . . . Zn=Z
{LHA less than 180° . . . . . . Zn=360−Z

DECLINATION (0°-14°) SAME NAME AS LATITUDE

LAT 41°

LHA	0°			1°			2°			3°			4°			5°			6°			7°			8°			9°			10°		14°			LHA
	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Hc	d	Z	
	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	° ′	′	°	
0	49 00	+60	180	50 00	+60	180	51 00	+60	180	52 00	+60	180	53 00	+60	180	54 00	+60	180	55 00	+60	180	56 00	+60	180	57 00	+60	180	58 00	60	180	59 00	+60	63 00	+60	180	360
1	48 59	60	179	49 59	60	178	49 59	60	178	51 59	60	178	51 59	60	178	53 59	60	178	54 59	60	178	55 59	60	178	56 59	60	178	57 59	60	178	58 59	60	62 59	60	178	359
2	48 58	60	177	49 58	60	177	50 58	59	177	51 57	60	177	52 27	60	177	53 57	60	177	54 57	60	177	55 57	60	177	56 57	60	176	57 57	60	176	58 57	60	62 57	60	176	358
3	48 55	60	175	49 55	59	175	50 54	60	175	51 54	60	175	52 54	60	175	53 54	60	175	54 54	60	175	55 54	60	175	56 54	59	175	57 53	60	174	58 53	60	62 52	60	174	357
4	48 50	60	174	49 50	60	174	50 50	60	174	51 50	60	174	52 50	59	173	53 49	60	173	54 49	60	173	55 49	60	173	56 49	59	173	57 48	60	173	58 48	60	62 47	59	172	356
5	48 45	+60	172	49 45	+59	172	50 44	+60	172	51 44	+60	172	52 44	+59	172	53 43	+60	172	54 43	+60	171	55 43	+59	171	56 42	+60	171	57 42	59	171	58 41	+60	62 39	+59	169	355
6	48 38	60	171	49 38	60	171	50 38	59	171	51 37	60	170	52 37	59	170	53 36	60	170	54 36	59	170	55 35	59	169	56 34	60	169	57 34	59	169	58 33	59	62 30	59	167	354
7	48 31	59	169	49 30	60	169	50 30	59	169	51 29	59	169	52 28	59	169	53 27	60	168	54 27	59	168	55 26	59	168	56 25	59	167	57 24	59	167	58 23	59	62 19	59	165	353
8	48 22	59	168	49 21	59	168	50 20	59	167	51 19	60	167	52 19	59	167	53 18	59	167	54 17	59	166	55 16	59	166	56 15	58	166	57 13	59	165	58 12	59	62 07	58	163	352
9	48 12	59	166	49 11	59	166	50 10	59	166	51 09	59	166	52 08	58	165	53 06	59	165	54 05	59	165	55 04	59	164	56 03	58	164	57 01	59	164	58 00	58	61 53	58	161	351
10	48 01	+58	165	48 59	+59	165	49 58	+59	174	50 57	+59	164	51 56	+58	164	52 54	+59	163	53 53	+58	163	54 51	+58	163	55 49	+59	162	56 48	58	162	57 46	+58	61 38	+57	159	350
11	47 48	59	164	48 47	58	163	49 45	59	163	50 44	58	163	51 42	59	162	52 41	58	162	53 39	58	161	54 37	58	161	55 35	58	161	56 33	58	160	57 31	58	61 21	57	157	349
12	47 35	58	162	48 33	58	162	49 31	59	161	50 30	58	161	51 28	58	161	52 26	58	160	53 24	57	160	54 21	58	159	55 19	58	159	56 17	57	158	57 14	58	61 03	56	155	348
13	47 20	58	161	48 18	58	160	49 16	58	160	50 14	58	159	51 12	58	159	52 10	57	159	53 07	58	158	54 05	57	158	55 02	57	157	55 59	58	157	56 57	57	60 43	56	154	347
14	47 05	58	159	48 03	57	158	49 00	58	158	49 58	57	158	50 55	58	158	51 53	57	157	52 50	57	157	53 47	57	156	54 44	57	156	55 41	57	155	56 38	56	60 22	56	152	346
15	46 48	+58	158	47 46	+57	157	48 43	+57	157	49 40	+57	157	50 37	+57	156	51 34	+57	156	52 31	+57	155	53 28	+57	154	54 25	+56	154	55 21	+58	153	56 17	+56	60 00	+55	150	345
16	46 31	57	156	47 28	57	156	48 25	57	156	49 22	56	155	50 18	57	155	51 15	57	154	52 12	56	153	53 08	56	153	54 04	55	152	55 00	55	152	55 56	56	59 37	54	148	344
17	46 12	57	155	47 09	56	155	48 05	57	154	49 02	56	154	49 58	57	153	50 55	56	153	51 51	56	152	52 47	56	151	53 43	55	151	54 38	55	150	55 33	56	59 12	54	146	343
18	45 52	57	154	46 49	56	153	47 45	56	153	48 41	56	152	49 37	56	152	50 33	56	151	51 29	56	150	52 25	55	150	53 20	55	149	54 15	55	149	55 10	55	58 47	53	145	342

N. Lat. {LHA greater than 180° . . . Zn=Z
{LHA less than 180° . . . . . . Zn=360−Z

DECLINATION (0°-14°) SAME NAME AS LATITUDE

LAT 42°

LHA	0°			1°			2°			3°			4°			5°			6°			7°			8°			9°			10°		14°			LHA
	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Hc	d	Z	
	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	° ′	′	°	
0	48 00	+60	180	49 00	+60	180	50 00	+60	180	51 00	+60	180	52 00	+60	180	53 00	+60	180	54 00	+60	180	55 00	+60	180	56 00	+60	180	57 00	+60	180	58 00	+60	62 00	+60	180	360
1	47 59	60	179	48 59	60	179	49 59	60	178	50 59	60	178	51 59	60	178	52 59	60	178	53 59	60	178	54 59	60	178	55 59	60	178	56 59	60	178	57 59	60	61 59	60	178	359
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3	47 55	60	176	48 55	60	175	49 55	59	175	50 54	60	175	51 54	60	175	52 54	60	175	53 54	60	175	54 54	60	175	55 54	60	175	56 54	60	175	57 54	59	61 53	60	174	357
4	47 51	60	174	48 51	59	174	49 50	60	174	50 50	60	174	51 50	60	174	52 50	60	173	53 50	59	173	54 49	60	173	55 49	60	173	56 49	60	173	57 49	59	61 47	60	172	356
5	47 46	+59	173	48 45	+60	172	49 45	+60	172	50 45	+59	172	51 44	+60	172	52 44	+60	172	53 44	+59	172	54 43	+60	171	55 43	+59	171	56 42	60	171	57 42	+60	61 40	+59	170	355
6	47 39	60	171	48 39	59	171	49 38	60	171	50 38	59	171	51 37	60	170	52 37	59	170	53 36	60	170	54 36	59	170	55 35	60	169	56 35	59	169	57 34	60	61 31	60	168	354
7	47 32	59	170	48 31	60	169	49 31	59	169	50 30	59	169	51 29	60	169	52 29	59	169	53 28	59	168	54 27	60	168	55 27	59	168	56 26	59	167	57 25	59	61 21	59	168	353
8	47 23	59	168	48 22	60	168	49 22	59	168	50 21	59	167	51 20	59	167	52 19	59	167	53 18	59	167	54 17	59	166	55 16	59	166	56 15	59	166	57 14	59	61 09	59	164	352
9	47 13	59	167	48 12	60	166	49 12	59	166	50 11	59	166	51 10	58	166	52 08	59	165	53 07	59	165	54 06	59	165	55 05	59	164	56 04	58	164	57 02	59	60 56	58	162	351
10	47 03	+58	165	48 01	+59	165	49 00	+59	165	49 59	+59	164	50 58	+59	164	51 57	+58	164	52 55	+59	163	53 54	+58	163	54 52	+59	163	55 51	+58	162	56 49	+58	60 42	+57	160	350
11	46 51	58	164	47 49	59	164	48 48	58	163	49 47	58	163	50 45	58	163	51 43	59	162	52 42	58	162	53 40	58	161	54 38	58	161	55 36	59	161	56 35	57	60 25	58	158	349
12	46 38	58	162	47 36	59	162	48 35	58	162	49 33	58	161	50 31	58	161	51 29	58	161	52 27	58	160	53 25	58	160	54 23	58	159	55 21	58	159	56 19	57	60 08	57	156	348
13	46 24	58	161	47 22	58	161	48 20	58	160	49 18	58	160	50 16	58	159	51 14	58	159	52 12	57	159	53 09	58	158	54 07	57	158	55 04	58	157	56 02	57	59 49	57	154	347
14	46 09	58	160	47 07	57	159	48 04	58	159	49 02	58	158	50 00	57	158	50 57	58	156	51 55	57	157	52 52	57	157	53 49	57	156	54 46	57	156	55 43	57	59 29	58	153	346
15	[illegible]	+57	[illegible]	46 50	+58	[illegible]	47 48	+57	157	48 45	+57	157	49 42	+58	157	50 40	+57	[illegible]	51 37	+57	[illegible]	52 34	+57	155	53 31	+58	155	54 27	+57	154	55 24	+56	59 08	+56	151	345
16	45 35	58	157	46 33	57	156	47 30	57	156	48 27	57	156	49 24	57	155	50 21	57	155	51 18	56	154	52 14	57	154	53 11	56	153	54 07	56	152	55 03	56	58 46	55	149	344
17	45 17	57	155	46 14	57	155	47 11	57	155	48 08	57	154	49 05	56	154	50 01	57	153	50 58	56	153	51 54	56	152	52 50	56	151	53 46	56	151	54 42	55	58 22	55	147	343
18	44 58	57	154	45 55	57	154	46 52	56	153	47 48	56	153	48 44	57	152	49 41	56	152	50 37	55	151	51 32	56	151	52 28	56	150	53 24	55	149	54 19	55	57 58	53	146	342

Figure 13-12. Basic Altitude is 55°21′

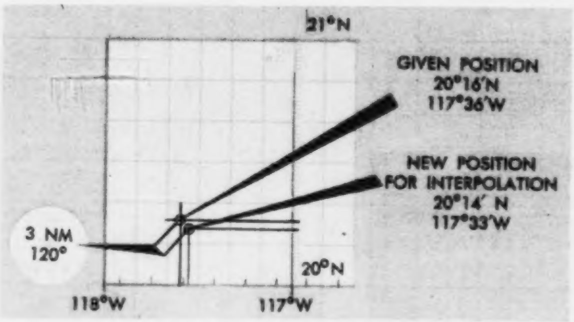


Figure 13-13. Adjust Original Position

/60 by the difference of Hc values to get the correction for the odd minutes of latitude.

3. The correction for LHA of Aries compares the original Hc with the Hc for 1° of LHA of Aries higher (same original latitude) to give the Hc correction for 60′ of LHA of Aries. Use this difference of Hc values and the odd number of minutes of LHA of Aries to obtain the correction for LHA of Aries. Again, if Volume II or III of H.O. 249 is available, use the table for odd minutes of declination to get the correction. If not, multiply the fraction *odd minutes of LHA Aries/*60 by the difference of Hc values to get the correction for the odd minutes of LHA of Aries.

4. This time only the corrections for latitude and the LHA of Aries are algebraically added to the original Hc. The new Hc is the correct Hc for the original position rather than for some assumed position.

Sample Problem. Here is a sample problem: The position is 20°16′ N, 117°36′ W, and Arcturus is the body. The date is 1 January and the time is 1310 GMT.

1. 1310 GHA Aries	297°53′
Longitude	−117°30′W
1310 LHA Aries	180°23′

The correction for precession/nutation is 3NM/300°. Make the adjustment as shown in figure 13-13. Now interpolate for 20°14′N, 117°33′W.

2. 1310 GHA Aries	297°53′
Longitude	−117°33′W
1310 LHA Aries	180°20′

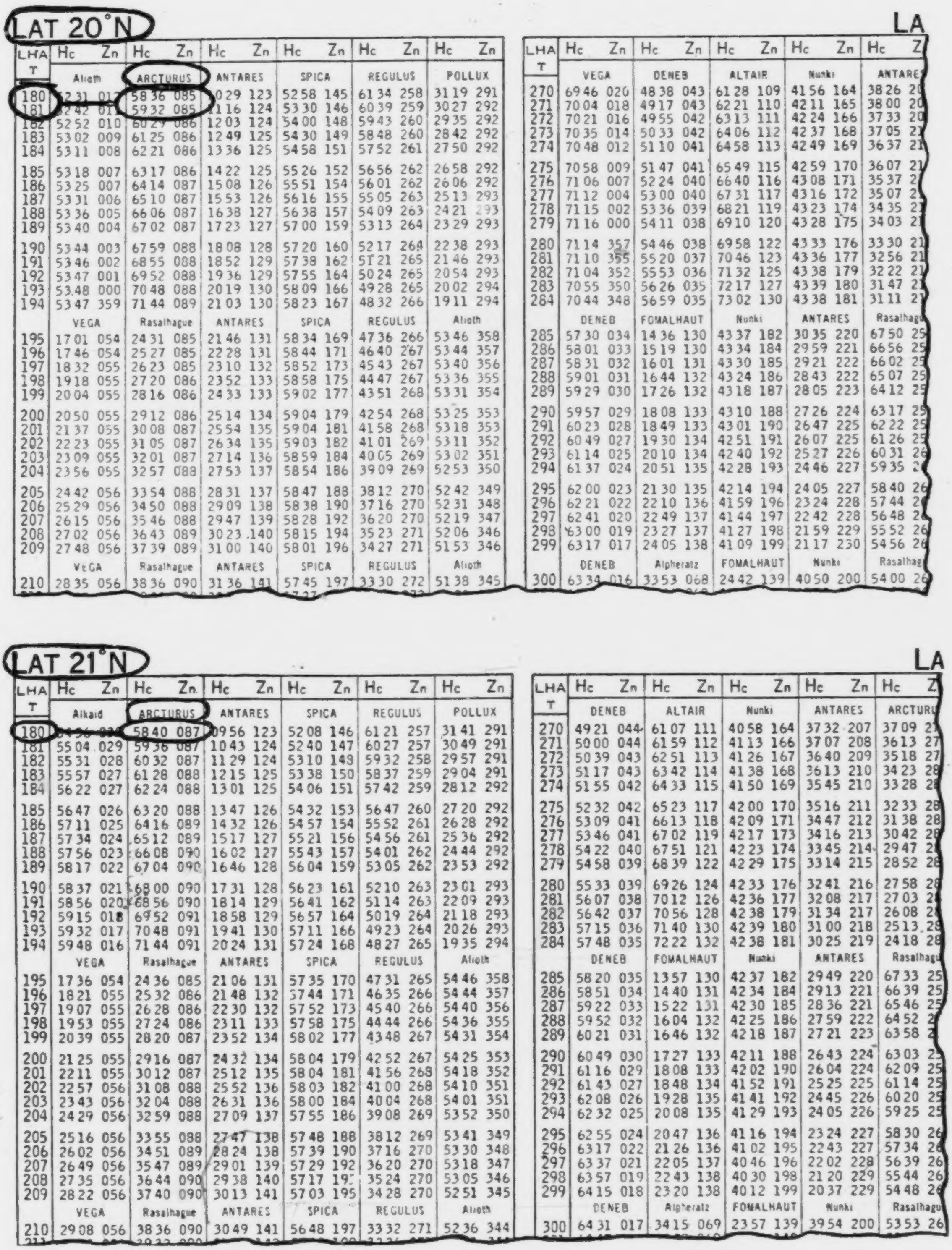
The basic latitude is 20° N, and the basic LHA of Aries is 180°. Using 180° LHA of Aries and latitude 20° N, the basic Hc of Arcturus is 58°36′, and Zn is 085° (refer to figure 13-14). Using 180° LHA of Aries and latitude 21° N, the Hc of Arcturus is 58°40′. The difference of Hc's is a +4 for 60′ of latitude. The fraction, 14/60, multiplied by +4 gives 14/15, or a 1′ correction for latitude.

3. Using 181° LHA of Aries and latitude 20° N, the Hc of Arcturus is 59°32′. Basic Hc of Arcturus is 58°36′. The difference of Hc's is a +56′ for 60′ of LHA of Aries. Multiplying the fraction 20/60, by +56 gives 18-2/3, or a +19′ correction for LHA of Aries.

4. Original Hc Arcturus	58°36′	
Corr for Lat	1′	(Step 2)
	58°37′	
Corr for LHA Aries	19′	(Step 3)
Final correct Hc Arcturus (for 20°16′ N, 117°36′ W, *not* for 20°14′ N, 117°33′ W)	58°56′	

SUMMARY

In the solutions in both the declination and star tables, the navigator is accomplishing the same thing. In the declination tables, he interpolates for the odd minutes of declination, latitude, and LHA. In the star tables, he interpolates for the odd minutes of latitude and LHA, and compensates for the slight annual change in the declination of the stars by applying precession/nutation correction. In doing this, the Hc and Zn are computed for a specific set of coordinates instead of adjusting the position, as is done in the ordinary solution.



LAT 20°N

LHA T	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn
	Alioth		ARCTURUS		ANTARES		SPICA		REGULUS		POLLUX	
180	52 31	[illegible]	58 36	085	10 29	123	52 58	145	61 34	258	31 19	291
181	52 42	[illegible]	59 32	085	11 16	124	53 30	146	60 39	259	30 27	292
182	52 52	010	60 29	086	12 03	124	54 00	148	59 43	260	29 35	292
183	53 02	009	61 25	086	12 49	125	54 30	149	58 48	260	28 42	292
184	53 11	008	62 21	086	13 36	125	54 58	151	57 52	261	27 50	292
185	53 18	007	63 17	086	14 22	125	55 26	152	56 56	262	26 58	292
186	53 25	007	64 14	087	15 08	126	55 51	154	56 01	262	26 06	292
187	53 31	006	65 10	087	15 53	126	56 16	155	55 05	263	25 13	293
188	53 36	005	66 06	087	16 38	127	56 38	157	54 09	263	24 21	293
189	53 40	004	67 02	087	17 23	127	57 00	159	53 13	264	23 29	293
190	53 44	003	67 59	088	18 08	128	57 20	160	52 17	264	22 38	293
191	53 46	002	68 55	088	18 52	129	57 38	162	51 21	265	21 46	293
192	53 47	001	69 52	088	19 36	129	57 55	164	50 24	265	20 54	293
193	53 48	000	70 48	088	20 19	130	58 09	166	49 28	265	20 02	294
194	53 47	359	71 44	089	21 03	130	58 23	167	48 32	266	19 11	294
	VEGA		Rasalhague		ANTARES		SPICA		REGULUS		Alioth	
195	17 01	054	24 31	085	21 46	131	58 34	169	47 36	266	53 46	358
196	17 46	054	25 27	085	22 28	131	58 44	171	46 40	267	53 44	357
197	18 32	055	26 23	085	23 10	132	58 52	173	45 43	267	53 40	356
198	19 18	055	27 20	086	23 52	133	58 58	175	44 47	267	53 36	355
199	20 04	055	28 16	086	24 33	133	59 02	177	43 51	268	53 31	354
200	20 50	055	29 12	086	25 14	134	59 04	179	42 54	268	53 25	353
201	21 37	055	30 08	087	25 54	135	59 04	181	41 58	268	53 18	353
202	22 23	055	31 05	087	26 34	135	59 03	182	41 01	269	53 11	352
203	23 09	055	32 01	087	27 14	136	58 59	184	40 05	269	53 02	351
204	23 56	055	32 57	088	27 53	137	58 54	186	39 09	269	52 53	350
205	24 42	056	33 54	088	28 31	137	58 47	188	38 12	270	52 42	349
206	25 29	056	34 50	088	29 09	138	58 38	190	37 16	270	52 31	348
207	26 15	056	35 46	088	29 47	139	58 28	192	36 20	270	52 19	347
208	27 02	056	36 43	089	30 23	140	58 15	194	35 23	271	52 06	346
209	27 48	056	37 39	089	31 00	140	58 01	196	34 27	271	51 53	346
	VEGA		Rasalhague		ANTARES		SPICA		REGULUS		Alioth	
210	28 35	056	38 36	090	31 36	141	57 45	197	33 30	272	51 38	345

LA

LHA T	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Z
	VEGA		DENEB		ALTAIR		Nunki		ANTARE	
270	69 46	020	48 38	043	61 28	109	41 56	164	38 26	20
271	70 04	018	49 17	043	62 21	110	42 11	165	38 00	20
272	70 21	016	49 55	042	63 13	111	42 24	166	37 33	20
273	70 35	014	50 33	042	64 06	112	42 37	168	37 05	21
274	70 48	012	51 10	041	64 58	113	42 49	169	36 37	21
275	70 58	009	51 47	041	65 49	115	42 59	170	36 07	21
276	71 06	007	52 24	040	66 40	116	43 08	171	35 37	2
277	71 12	004	53 00	040	67 31	117	43 16	172	35 07	2
278	71 15	002	53 36	039	68 21	119	43 23	174	34 35	2
279	71 16	000	54 11	038	69 10	120	43 28	175	34 03	2
280	71 14	357	54 46	038	69 58	122	43 33	176	33 30	21
281	71 10	355	55 20	037	70 46	123	43 36	177	32 56	21
282	71 04	352	55 53	036	71 32	125	43 38	179	32 22	21
283	70 55	350	56 26	035	72 17	127	43 39	180	31 47	21
284	70 44	348	56 59	035	73 02	130	43 38	181	31 11	21
	DENEB		FOMALHAUT		Nunki		ANTARES		Rasalhagu	
285	57 30	034	14 36	130	43 37	182	30 35	220	67 50	25
286	58 01	033	15 19	130	43 34	184	29 59	221	66 56	25
287	58 31	032	16 01	131	43 30	185	29 21	222	66 02	25
288	59 01	031	16 44	132	43 24	186	28 43	222	65 07	25
289	59 29	030	17 26	132	43 18	187	28 05	223	64 12	25
290	59 57	029	18 08	133	43 10	188	27 26	224	63 17	25
291	60 23	028	18 49	133	43 01	190	26 47	225	62 22	25
292	60 49	027	19 30	134	42 51	191	26 07	225	61 26	25
293	61 14	025	20 10	134	42 40	192	25 27	226	60 31	26
294	61 37	024	20 51	135	42 28	193	24 46	227	59 35	2
295	62 00	023	21 30	135	42 14	194	24 05	227	58 40	26
296	62 21	022	22 10	136	41 59	196	23 24	228	57 44	2
297	62 41	020	22 49	137	41 44	197	22 42	228	56 48	2
298	63 00	019	23 27	137	41 27	198	21 59	229	55 52	26
299	63 17	017	24 05	138	41 09	199	21 17	230	54 56	26
	DENEB		Alpheratz		FOMALHAUT		Nunki		Rasalhag	
300	63 34	016	33 53	068	24 42	139	40 50	200	54 00	26

LAT 21°N

LHA T	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn
	Alkaid		ARCTURUS		ANTARES		SPICA		REGULUS		POLLUX	
180	[illegible]	[illegible]	58 40	087	09 56	123	52 08	146	61 21	257	31 41	291
181	55 04	029	59 36	087	10 43	124	52 40	147	60 27	257	30 49	291
182	55 31	028	60 32	087	11 29	124	53 10	148	59 32	258	29 57	291
183	55 57	027	61 28	088	12 15	125	53 38	150	58 37	259	29 04	291
184	56 22	027	62 24	088	13 01	125	54 06	151	57 42	259	28 12	292
185	56 47	026	63 20	088	13 47	126	54 32	153	56 47	260	27 20	292
186	57 11	025	64 16	089	14 32	126	54 57	154	55 52	261	26 28	292
187	57 34	024	65 12	089	15 17	127	55 21	156	54 56	261	25 36	292
188	57 56	023	66 08	090	16 02	127	55 43	157	54 01	262	24 44	292
189	58 17	022	67 04	090	16 46	128	56 04	159	53 05	262	23 53	292
190	58 37	021	68 00	090	17 31	128	56 23	161	52 10	263	23 01	293
191	58 56	020	68 56	090	18 14	129	56 41	162	51 14	263	22 09	293
192	59 15	018	69 52	091	18 58	129	56 57	164	50 19	264	21 18	293
193	59 32	017	70 48	091	19 41	130	57 11	166	49 23	264	20 26	293
194	59 48	016	71 44	091	20 24	131	57 24	168	48 27	265	19 35	294
	VEGA		Rasalhague		ANTARES		SPICA		REGULUS		Alioth	
195	17 36	054	24 36	085	21 06	131	57 35	170	47 31	265	54 46	358
196	18 21	055	25 32	086	21 48	132	57 44	171	46 35	266	54 44	357
197	19 07	055	26 28	086	22 30	132	57 52	173	45 40	266	54 40	356
198	19 53	055	27 24	086	23 11	133	57 58	175	44 44	266	54 36	355
199	20 39	055	28 20	087	23 52	134	58 02	177	43 48	267	54 31	354
200	21 25	055	29 16	087	24 32	134	58 04	179	42 52	267	54 25	353
201	22 11	055	30 12	087	25 12	135	58 04	181	41 56	268	54 18	352
202	22 57	056	31 08	088	25 52	136	58 03	182	41 00	268	54 10	351
203	23 43	056	32 04	088	26 31	136	58 00	184	40 04	268	54 01	351
204	24 29	056	32 59	088	27 09	137	57 55	186	39 08	269	53 52	350
205	25 16	056	33 55	088	27 47	138	57 48	188	38 12	269	53 41	349
206	26 02	056	34 51	089	28 24	138	57 39	190	37 16	270	53 30	348
207	26 49	056	35 47	089	29 01	139	57 29	192	36 20	270	53 18	347
208	27 35	056	36 44	090	29 38	140	57 17	19	35 24	270	53 05	346
209	28 22	056	37 40	090	30 13	141	57 03	195	34 28	270	52 51	345
	VEGA		Rasalhague		ANTARES		SPICA		REGULUS		Alioth	
210	29 08	056	38 36	090	30 49	141	56 48	197	33 32	271	52 36	344

LA

LHA T	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Z
	DENEB		ALTAIR		Nunki		ANTARES		ARCTURU	
270	49 21	044	61 07	111	40 58	164	37 32	207	37 09	2
271	50 00	044	61 59	112	41 13	166	37 07	208	36 13	27
272	50 39	043	62 51	113	41 26	167	36 40	209	35 18	27
273	51 17	043	63 42	114	41 38	168	36 13	210	34 23	28
274	51 55	042	64 33	115	41 50	169	35 45	210	33 28	28
275	52 32	042	65 23	117	42 00	170	35 16	211	32 33	28
276	53 09	041	66 13	118	42 09	171	34 47	212	31 38	28
277	53 46	041	67 02	119	42 17	173	34 16	213	30 42	28
278	54 22	040	67 51	121	42 23	174	33 45	214	29 47	2
279	54 58	039	68 39	122	42 29	175	33 14	215	28 52	28
280	55 33	039	69 26	124	42 33	176	32 41	216	27 58	2
281	56 07	038	70 12	126	42 36	177	32 08	217	27 03	2
282	56 42	037	70 56	128	42 38	179	31 34	217	26 08	2
283	57 15	036	71 40	130	42 39	180	31 00	218	25 13	28
284	57 48	035	72 22	132	42 38	181	30 25	219	24 18	28
	DENEB		FOMALHAUT		Nunki		ANTARES		Rasalhagu	
285	58 20	035	13 57	130	42 37	182	29 49	220	67 33	25
286	58 51	034	14 40	131	42 34	184	29 13	221	66 39	25
287	59 22	033	15 22	131	42 30	185	28 36	221	65 46	25
288	59 52	032	16 04	132	42 25	186	27 59	222	64 52	2
289	60 21	031	16 46	132	42 18	187	27 21	223	63 58	2
290	60 49	030	17 27	133	42 11	188	26 43	224	63 03	2
291	61 16	029	18 08	133	42 02	190	26 04	224	62 09	25
292	61 43	027	18 48	134	41 52	191	25 25	225	61 14	25
293	62 08	026	19 28	135	41 41	192	24 45	226	60 20	25
294	62 32	025	20 08	135	41 29	193	24 05	226	59 25	25
295	62 55	024	20 47	136	41 16	194	23 24	227	58 30	26
296	63 17	022	21 26	136	41 02	195	22 43	227	57 34	26
297	63 37	021	22 05	137	40 46	196	22 02	228	56 39	26
298	63 57	019	22 43	138	40 30	198	21 20	229	55 44	26
299	64 15	018	23 20	138	40 12	199	20 37	229	54 48	26
	DENEB		Alpheratz		FOMALHAUT		Nunki		Rasalhagu	
300	64 31	017	34 15	069	23 57	139	39 54	200	53 53	26

Figure 13-14. Adjust Basic Altitude

CHAPTER 14

Plotting and Interpreting Celestial LOPs

PLOTTING LOPS

In the preceding chapters the steps necessary to obtain the Hc, Zn, and assumed position are discussed. Also a brief explanation on how to construct a line of position (LOP) is given. There are several techniques involved in plotting LOPs which are discussed separately. One such technique is the subpoint method.

The Subpoint Method

The theory involved in this method has previously been discussed. Here is a summary of the steps involved:

1. The navigator measures the altitude (Hs) of a celestial body with the sextant and notes the exact midtime of the observation. By applying the appropriate corrections to Hs, the Ho is obtained. (Corrections for parallax, refraction, semidiameter, and wander are explained in Chapter 15, Sextants and Errors of Observation.)
2. The Ho is subtracted from 90° to find the co-altitude of the body. The co-altitude is converted to nautical miles (1° equals 60NM) to find the distance from the subpoint of the body observed, as shown in figure 14-1.
3. From the *Air Almanac* the declination and GHA of the body are extracted for the time of observation. These values are converted to the geographical coordinates of the subpoint. The declination is the latitude of the subpoint, and the GHA is the longitude of the subpoint west of Greenwich. (When the GHA is greater than 180°, subtract it from 360° to get east longitude.)
4. The subpoint of the body is plotted on the chart.
5. Using the subpoint as a center and using the distance from the subpoint as a radius, an arc is scribed in the vicinity of the DR position to obtain the LOP.

When the altitude of the body is near 90°, the LOP is drawn by swinging an arc from the subpoint. Often, however, bodies will be observed at lower altitudes. Then it is impracticable to draw LOPs by this method, as explained in the following paragraph.

If a body is observed at 20° above the horizon, the observer is 4,200 nautical miles from its subpoint. To swing an LOP from this subpoint, the subpoint and the arc must be plotted on the same chart. To permit plotting of any LOP, the chart must cover an area extending more than 4,000 miles in every direction from the DR position. This means that the chart must be either of such large size that it cannot be spread out on a table in the aircraft, or of such small scale that plotting on it is inaccurate. To cover an area 8,000 miles across, a chart 4 feet square must be drawn to a scale of about 1:10,000,000. Furthermore, measuring would be difficult because of distortion.

Since a celestial LOP cannot always be drawn by swinging an arc from the subpoint, the intercept method, which is based on the same principles as the subpoint method, is often used.

The Intercept Method

It is possible to compute, by trigonometry, the position of an LOP and then draw the LOP on a chart without plotting the subpoint. Although this is a direct method of obtaining an LOP, the computation is complicated and slow, and is not suitable for use in flight. The intercept method is indirect and roundabout, but it can be worked rapidly by means of tables and, therefore, is suitable for use in flight.

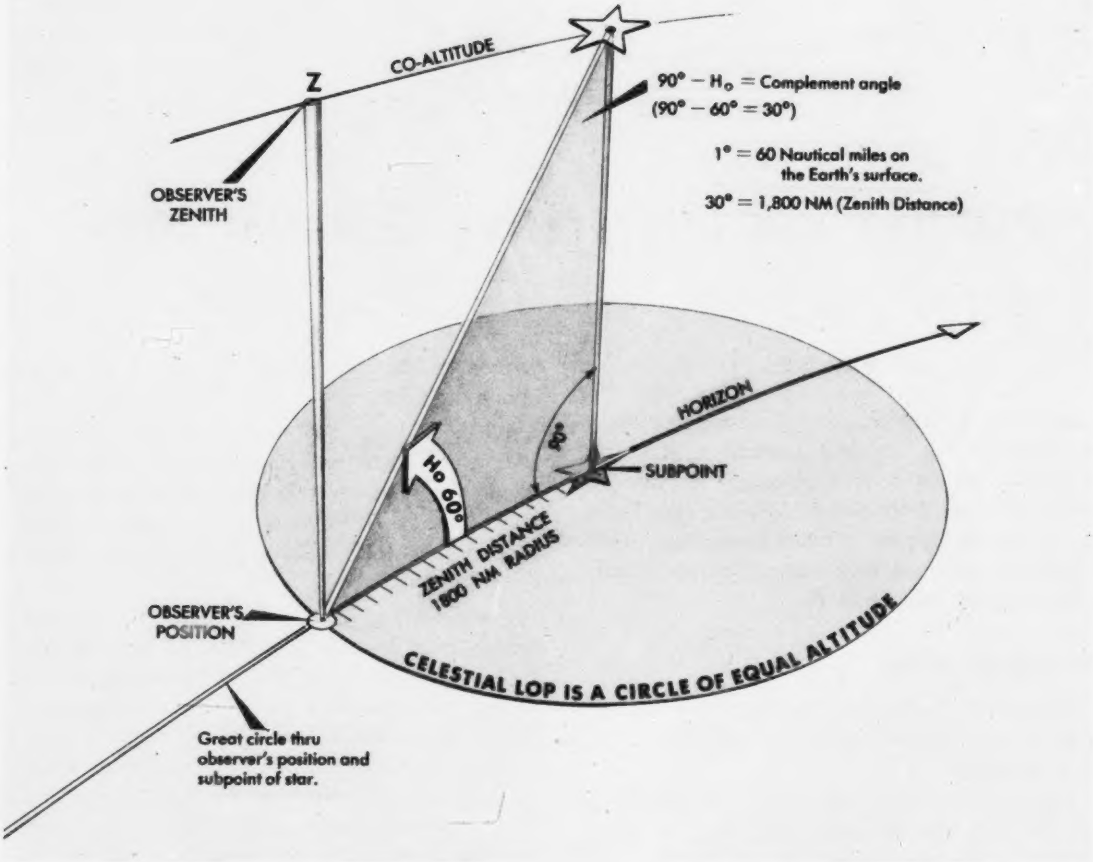

CO-ALTITUDE
Z
90° − H_o = Complement angle
(90° − 60° = 30°)
1° = 60 Nautical miles on the Earth's surface.
30° = 1,800 NM (Zenith Distance)
OBSERVER'S ZENITH
HORIZON
90°
Ho 60°
SUBPOINT
ZENITH DISTANCE
1800 NM RADIUS
OBSERVER'S POSITION
CELESTIAL LOP IS A CIRCLE OF EQUAL ALTITUDE
Great circle thru observer's position and subpoint of star.

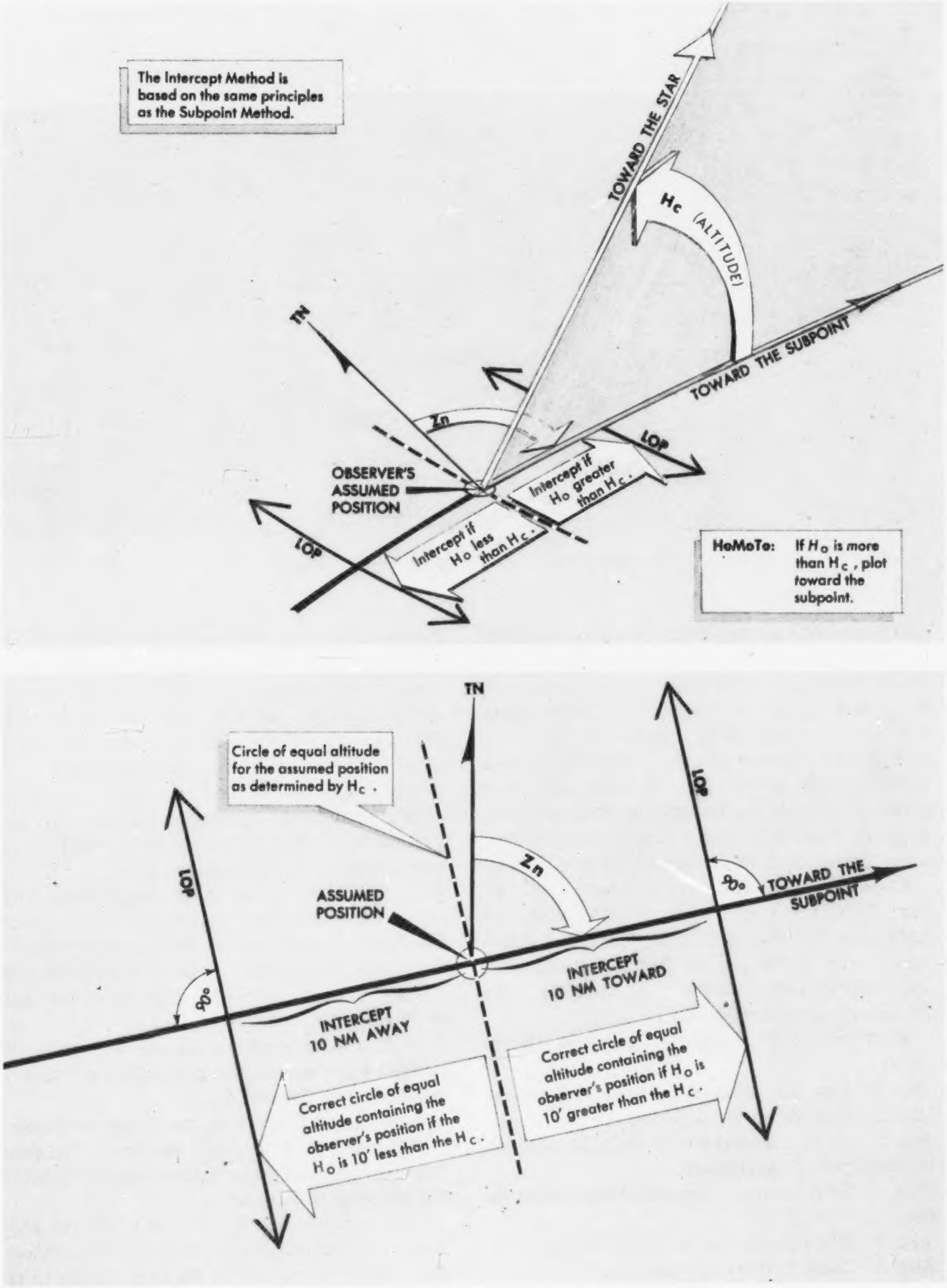
Figure 14-1. The Subpoint Method

There are several variations and refinements of this method, but the basic concepts are the same. In the determination of an LOP, an assumed position is selected. With the celestial tables, determine the altitude (Hc) and true azimuth (Zn) that would be observed if the observer were at this assumed position (see Chapter 13, Computing Altitude and True Azimuth). In other words, the Hc obtained is the Ho that the observer would read if he were on the circle of equal altitude that goes through the assumed position. The true azimuth (Zn) obtained will closely approximate the direction of the subpoint from the assumed position.

A comparison of the Ho and the Hc gives a difference in minutes or nautical miles called the *intercept.* Since the Ho determines the correct circle of equal altitude, the intercept tells the observer that the circle of equal altitude he is actually on is closer to or farther from the subpoint than the assumed position by the value of the intercept. If the Ho is *greater* than the Hc, he is closer to the subpoint, and the intercept is measured *toward* the subpoint. By the same reasoning, when the Ho is *less* than the Hc, the intercept is measured *away* from the subpoint, as shown in figure 14-2.

NOTE: If Ho is more than Hc, plot toward the subpoint (HoMoTo).

An intercept toward the body is in the direction of the true azimuth. An intercept away from the body is in a direction 180° from the true azimuth. Therefore, if the assumed position is plotted as in figure 14-3 and if the observer moves the intercept



The Intercept Method is based on the same principles as the Subpoint Method.

HoMoTo: If H_o is more than H_c, plot toward the subpoint.

TOWARD THE STAR
Hc (ALTITUDE)
TOWARD THE SUBPOINT
TN
Zn
LOP
OBSERVER'S ASSUMED POSITION
Intercept if Ho greater than Hc.
Intercept if Ho less than Hc.
LOP

Circle of equal altitude for the assumed position as determined by H_c.

Correct circle of equal altitude containing the observer's position if the H_o is 10′ less than the H_c.

Correct circle of equal altitude containing the observer's position if H_o is 10′ greater than the H_c.

TN
LOP
LOP
Zn
ASSUMED POSITION
90°
90°
TOWARD THE SUBPOINT
INTERCEPT 10 NM TOWARD
INTERCEPT 10 NM AWAY

Figure 14-2. LOP Computed by Intercept Method

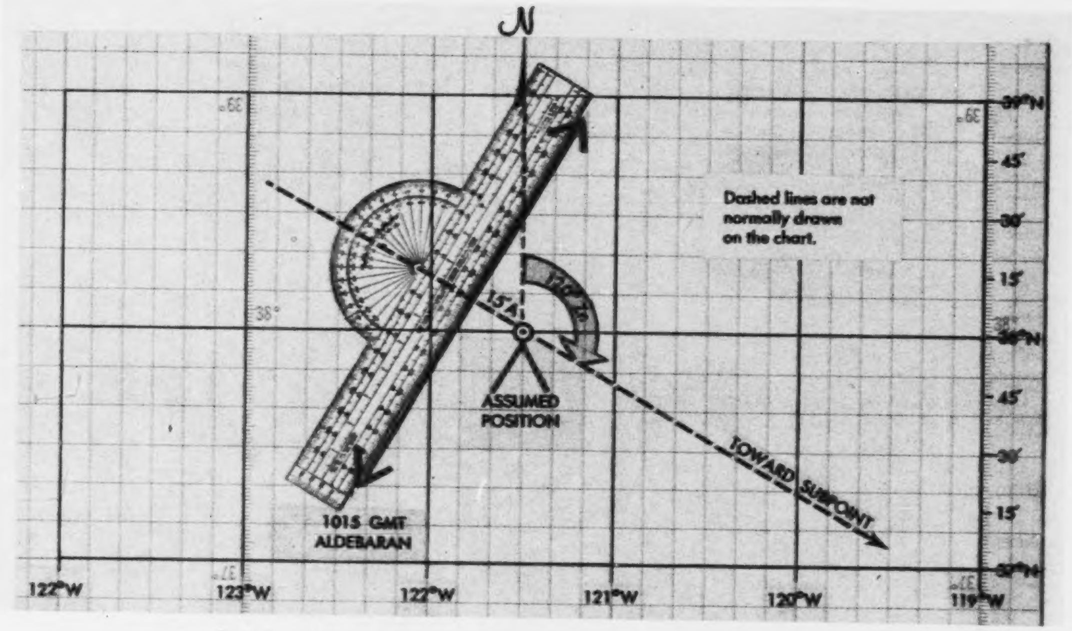


Figure 14-3. Celestial LOP Using Zn Method

distance toward or away from the direction of true azimuth, a point is located on the circle of equal altitude that contains the actual position. A straight line is then constructed perpendicular to the direction of the true azimuth to represent the arc of the correct circle of equal altitude. This is the celestial LOP. The arc of the circle of equal altitude is drawn as a straight line because the circle is so very large for most shots that a straight line approximates the arc itself over relatively short distances.

Example: The assumed position is 38° N, 121°30′ W for a shot taken at 1015 GMT on Aldebaran. The Ho is 32°14′. The Hc is determined to be 32°29′ and the Zn 120°. A comparison of Ho and Hc determines the intercept to be 15 nautical miles away (15′A).

PLOTTING LOP USING ZN METHOD (figure 14-3).

Step 1. Plot the assumed position and set the intercept distance on the dividers.

Step 2. Draw a dashed line through the assumed position toward the subpoint.

Step 3. Span intercept distance along dashed Zn line.

Step 4. Place plotter perpendicular to Zn.

Step 5. Draw LOP along plotter as shown.

PLOTTING LOP USING FLIP FLOP METHOD (figure 14-4).

Step 1. Plot the assumed position and set the intercept distance on the dividers.

Step 2. With point A of the dividers on the assumed position, measure 120° of the Zn and place point B of the dividers down, in this case, *away* from 120° or in the direction of 300° from the assumed position. Slide the plotter along the dividers until the center grommet and the 100/200 mile mark are lined up directly over point B of the dividers marking the intercept point.

Step 3. Remove point A of the dividers from the assumed position, keeping point B in place. Flip point A (that was on the assumed position) across the plotter, at the same time expanding the dividers so that point A can be placed on the chart at the 90°/270° mark of the plotter.

Step 4. Flop the plotter around and place the straight edge against the perpendicular which is established by the dividers.

Step 5. Draw LOP along the plotter as shown.

SUMMARY OF INTERCEPT METHOD. The main steps to remember when determining the LOP by the intercept method are:

1. Measure the altitude (Hs) of a celestial body with a sextant and note the midtime of the observation. Apply corrections to Hs or pre-apply to Hc to obtain Ho and record the time of observation, the body observed, and the Ho of the body.

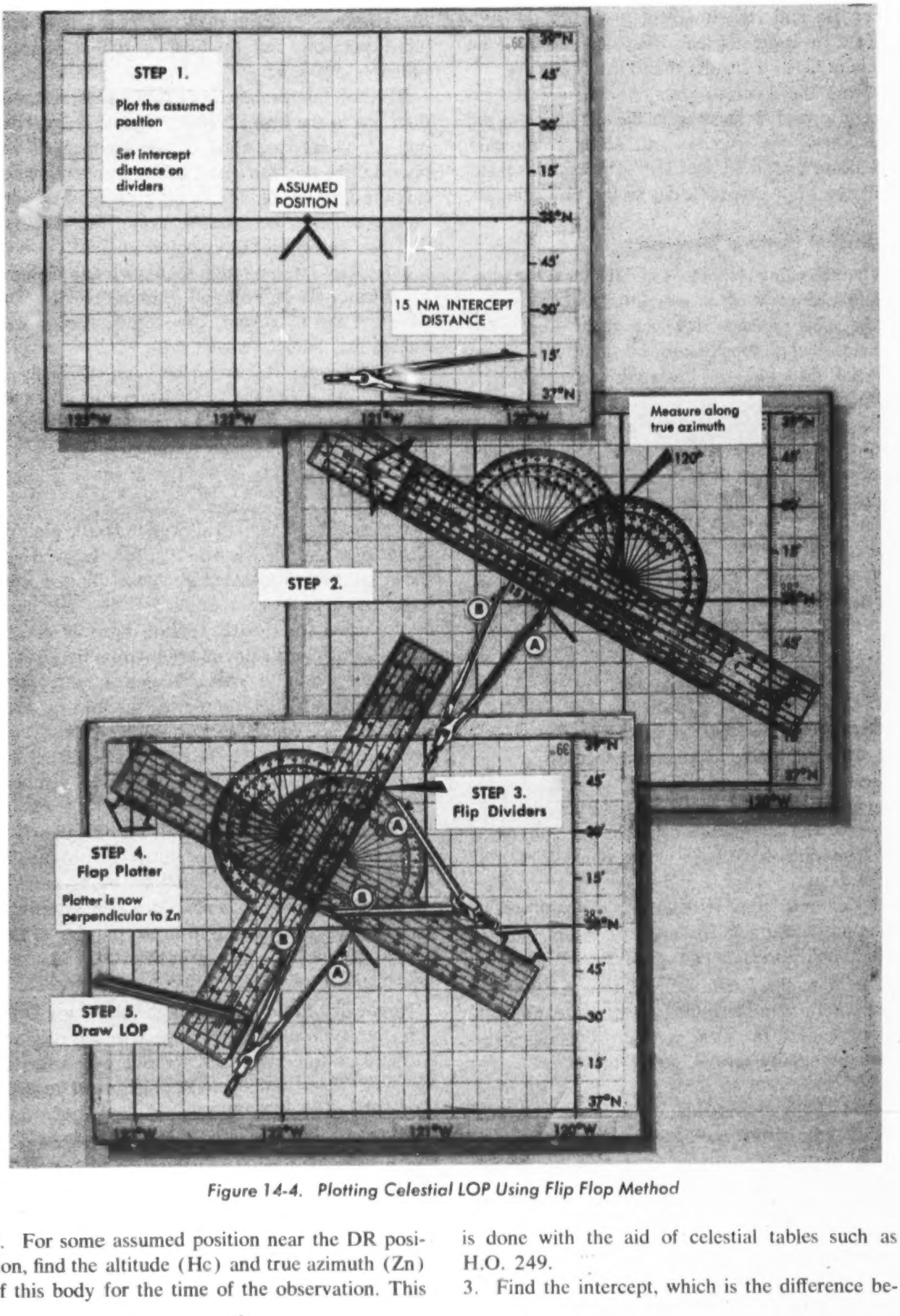

STEP 1.
Plot the assumed position
Set intercept distance on dividers
ASSUMED POSITION
15 NM INTERCEPT DISTANCE
39°N
45'
30'
15'
38°N
45'
30'
15'
37°N
123°W
122°W
121°W
120°W
Measure along true azimuth
120°
STEP 2.
A
B
STEP 3.
Flip Dividers
STEP 4.
Flop Plotter
Plotter is now perpendicular to Zn
STEP 5.
Draw LOP

Figure 14-4. Plotting Celestial LOP Using Flip Flop Method

2. For some assumed position near the DR position, find the altitude (Hc) and true azimuth (Zn) of this body for the time of the observation. This is done with the aid of celestial tables such as H.O. 249.

3. Find the intercept, which is the difference be-

tween Ho and Hc. Intercept is *toward* the subpoint if Ho is greater than Hc, and *away* from the subpoint if Ho is smaller than Hc.

4. From the assumed position, measure the intercept toward or away from the subpoint (in the direction of the true azimuth or its reciprocal) and locate a point on the LOP. Through this point draw the LOP perpendicular to the true azimuth.

Additional Plotting Techniques

The preceding techniques involve the basic plotting procedures used on most stars and the bodies of the solar system. However, there are certain techniques of plotting that are peculiar to their own celestial methods; for example, the plotting of LOPs obtained by using Polaris which is discussed later. Also certain precomputation techniques lend themselves readily to other plotting techniques, such as preplotting the true azimuths or plotting the fix on the DR computer.

These last plotting techniques are discussed in the section on H.O. 249 Precomputation. Other special techniques are discussed in the section on curves, in which the celestial observation is plotted on a graph rather than on the chart.

INTERPRETATION OF LOP

Navigation has two aspects, the mechanical and the interpretive. The mechanical aspect includes operation and reading of instruments, simple arithmetical calculations, plotting, and log keeping. The interpretive aspect is the analysis of the data which have been gathered mechanically. These data are variable and subject to error. The navigator must convert them into probabilities as to the position, track, and groundspeed of the aircraft, and the direction and speed of the wind.

The more these data are subject to error, the more careful the interpretations must be; and the less mechanical the work can be. LOPs and fixes especially require careful interpretation.

It is convenient to think of a fix as the true position of the aircraft and of the LOP as a line passing through this position, but these definitions are optimistic. It is almost impossible to make a perfect observation and plot a perfect LOP. Therefore, an LOP passes some place *near* this position, but not necessarily through it, and a fix determined by the intersection of LOPs is simply the *best estimate* of this position on the basis of one set of observations. Thus, in reality, a fix is a most probable position, and an LOP is a line of most probable position.

The best interpretation of LOPs and fixes means their use to the best advantage with dead reckoning. Good interpretation cannot compensate for poor LOPs, nor can good LOPs compensate for careless dead reckoning. To get good results, every precaution must be taken to insure the accuracy of LOPs and exact DR calculations.

Intelligent interpretation requires fine judgment, which can only be acquired from experience. The navigator can be guided, however, by certain well established, though flexible rules.

The following discussion pertains especially to celestial LOPs and fixes. It also applies to LOPs and fixes established by radio, and, to some extent, to those obtained by map reading.

Single LOP

Previous discussions dealt with the basic plotting of an LOP and errors in LOPs, but they did not show the actual mechanics of the plotted corrections which must be applied. The LOP must be corrected for Coriolis/rhumb line correction, and also for precession/nutation correction if it is based on an H.O. 249, Volume I, star shot. Coriolis/rhumb line correction becomes a very significant correction at higher speeds and latitudes. Suppose the correction determined from the Coriolis/rhumb line correction table is 9 nautical miles right (of the track). The LOP must be moved a distance of 9 nautical miles to the right of track. This can be done either by moving the assumed position prior to plotting, or by moving the LOP itself after it is plotted. (Remember the assumed position is not used in the plotting of the LOP obtained from a Polaris observation.) Consider figure 14-5, which shows a track of 90°.

Notice that in both methods the corrected LOP is in the same place with respect to the original assumed position, and that the intercept value is the same. The resultant LOP is the same regardless of the method used.

If, in addition to the Coriolis/rhumb line correction, a precession/nutation correction of 3 nautical miles in the direction of 60° is required, it would have been further applied as shown in figure 14-6. Again the corrected LOP is the same, using either method, because the intercept and resultant position of the corrected LOP to the original assumed

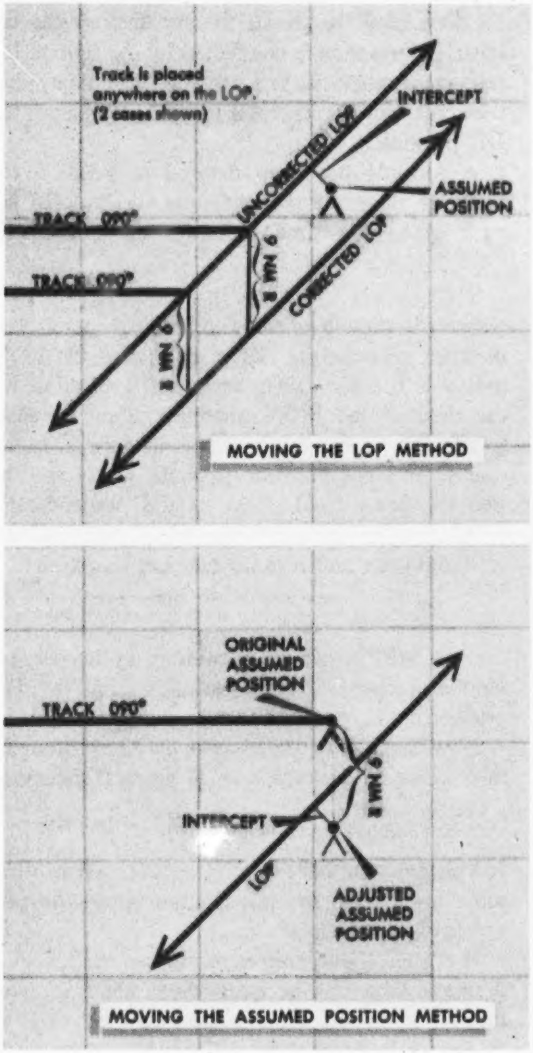

Track is placed anywhere on the LOP. (2 cases shown)
INTERCEPT
UNCORRECTED LOP
ASSUMED POSITION
TRACK 090°
TRACK 090°
9 NM R
CORRECTED LOP
9 NM R
MOVING THE LOP METHOD
ORIGINAL ASSUMED POSITION
TRACK 090°
9 NM R
INTERCEPT
LOP
ADJUSTED ASSUMED POSITION
MOVING THE ASSUMED POSITION METHOD

Figure 14-5. Two Methods of Coriolis/Rhumb Line Correction

position are the same. The corrected LOP alone gives very little information; hence, a position must be arrived at only after considering the LOP and the DR position for the same time. There is also a special use for the single LOP which is discussed in the section on landfalls.

Most Probable Position (MPP) By C-Plot

The most probable position is just what the name implies. It is not a fix; however, since it is the best information available, it is treated as such. Notice in figure 14-7A that the DR position and celestial LOP (for the same time) do not coincide.

Obviously, the DR information or celestial information, or both, are in error. Notice that the prior fix has no time on it. Suppose this prior fix had been for the time of 1010. It would then be very likely that most of the error is in the celestial information and the probable position is closer to the DR position than to the celestial LOP. On the other hand, suppose the prior fix had been for

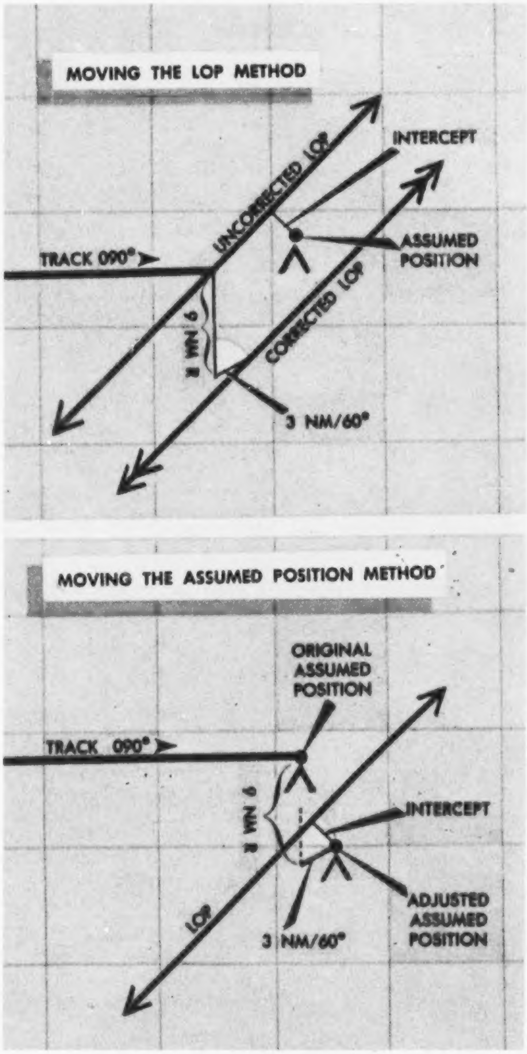

MOVING THE LOP METHOD
INTERCEPT
UNCORRECTED LOP
ASSUMED POSITION
TRACK 090°
9 NM R
CORRECTED LOP
3 NM/60°
MOVING THE ASSUMED POSITION METHOD
ORIGINAL ASSUMED POSITION
TRACK 090°
9 NM R
INTERCEPT
ADJUSTED ASSUMED POSITION
3 NM/60°
LOP

Figure 14-6. Two Corrections — Coriolis/Rhumb Line and Precession/Nutation

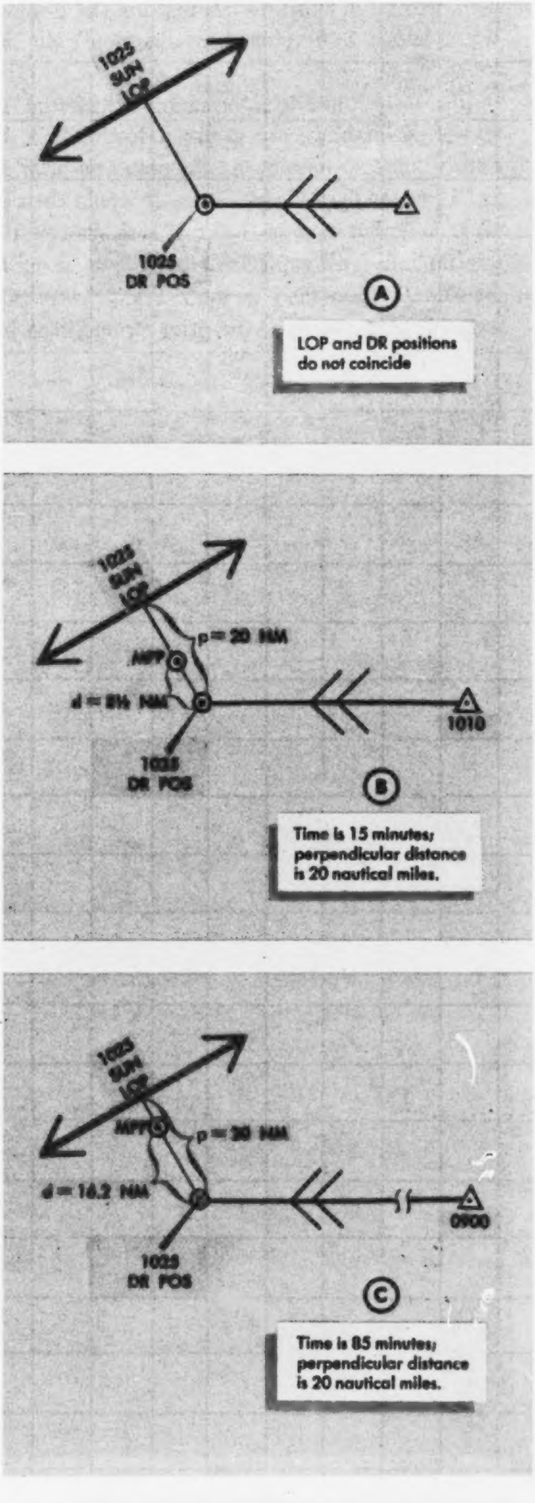

1025
SUN
LOP
1025
DR POS
A
LOP and DR positions do not coincide
1025
SUN
LOP
p = 20 NM
MPP
d = 8½ NM
1010
1025
DR POS
B
Time is 15 minutes; perpendicular distance is 20 nautical miles.
1025
SUN
LOP
MPP
p = 20 NM
d = 16.2 NM
0900
1025
DR POS
C
Time is 85 minutes; perpendicular distance is 20 nautical miles.

Figure 14-7. Most Probable Position (MPP) by C-Plot

the time of 0900. Since the accuracy of the celestial information is unaffected by the time to the last fix, it would in this case be most likely that the actual position is closer to the LOP than to the DR position.

A formula has been devised to position the observer along the perpendicular to the LOP according to the time factor. The formula is

$$\frac{d}{t} = \frac{p}{t + p}$$

where t is time in minutes, p is the perpendicular distance between the DR position and the LOP, and d is the distance from the DR position for the time of the MPP measured along the perpendicular to the LOP. Look at figures 14-7B and C and see how the formula works for the two problems cited above if the perpendicular is 20 nautical miles in length. In figure 14-7B, t is 15 minutes and p is 20 nautical miles, so

$$\frac{d}{15} = \frac{20}{15 + 20} \qquad d = \frac{300}{35} = 8.57 \text{ NM}$$

and the MPP would be located along the perpendicular about 8½ nautical miles from the DR position.

Now consider figure 14-7C where t is 1 hour 25 minutes or 85 minutes, p is 20 nautical miles and

$$\frac{d}{20} = \frac{85}{20 + 85} \qquad d = \frac{1700}{105} = 16.2 \text{ NM}$$

In this case the MPP would be over 16 nautical miles away from the DR position along the perpendicular to the LOP.

If the navigator prefers not to use the formula, a simple table can be easily constructed to solve for "d" with entering arguments of "p" and "t" as shown in figure 14-8. The table could easily be enlarged to handle larger values of "t" and "p."

In most fixes, the DR position is so close to the LOP that the midpoint between these two can be considered the MPP. A good rule to use is to take the midpoint of the perpendicular if the total distance between the DR position and the LOP is 10 nautical miles or less. If the value of p is greater than 10 nautical miles, the formula

$$\frac{d}{t} = \frac{p}{t + p}$$

or a table based on this formula should be used to determine the MPP.

Up to this point, determination of the MPP has been rather mechanical. Experienced navigators will frequently further adjust the position of the MPP for other factors not yet considered. For

P ▼	"t"—TIME IN MINUTES			
	10m	15m	30m	60m
12	5	7	9	10
14	6	7	10	11
16	6	8	10	13
18	6	8	11	14
20	7	9	12	15
25	7	9	14	18
30	8	10	15	20
35	8	10	16	22
40	8	11	17	24
45	8	11	18	26
50	8	12	19	27
55	9	12	19	29
60	9	12	20	30
To the closest NM values of "d" in the formula.				

Figure 14-8. To Solve for Distance ("d")

example, if the LOP is carefully obtained under good conditions or if it is the average of several LOPs, he may further weight the MPP in the direction of the LOP by the amount his judgment dictates. However, the reverse may be true if the LOP is obtained under adverse conditions of rough air. In the latter case, he might move the MPP closer to the DR position by some amount determined by his judgment.

Further, consider the validity of the DR position in relation to factors other than time. A DR position at the end of 40 minutes would be more reliable with drift and groundspeed by timing than one based on metro information. These factors may also adjust the original MPP closer to or farther away from the DR position, along the perpendicular. However, these last mentioned factors are judgment values that come only with experience. In fact, the experienced navigator may mentally calculate all the factors involved and arrive at the final position of the MPP without recourse to the formula or table.

Finding a Celestial Fix Point

Up to this point only the single celestial LOP and what to do with it have been considered. Now, the celestial fix should be considered. To establish a fix, two or more lines of position must be obtained. Since, in most cases two or more LOPs cannot be obtained simultaneously, they must be converted to a common time. For example, an LOP obtained at 1010 must be converted to the LOP obtained at the fix time of 1014. There are several methods for making this conversion which are discussed presently. Consideration is also given to the planning of the fix and the final interpretation of the fix itself.

CONVERSION OF LOPS TO A COMMON TIME. *Moving LOP.* One method of converting LOPs to a common time is to move the LOP along the best known track for the number of minutes of groundspeed necessary for the time conversions. This method is similar to that used for correcting for Coriolis/rhumb line and precession/nutation. For example, suppose the track is 110°, and the groundspeed 300 knots. LOPs are for 1500, 1504, and 1508, and a fix is desired at 1508. This means the 1500 LOP must be moved to the time of the fix, using the track and 8 minutes of the best known groundspeed. The 1504 LOP must be moved to the time of the fix, using the track and 4 minutes of groundspeed. The 1508 LOP is already at the fix time, so it requires no movement. Figure 14-9 shows the method of conversion as it is completed on the chart.

If at any time the LOP has to be retarded (moved back) to the time of the fix, use the following procedures. Using the reciprocal track and groundspeed, obtain the correction in the regular manner for the number of minutes of difference. For example, suppose the fix is at 1800 and the

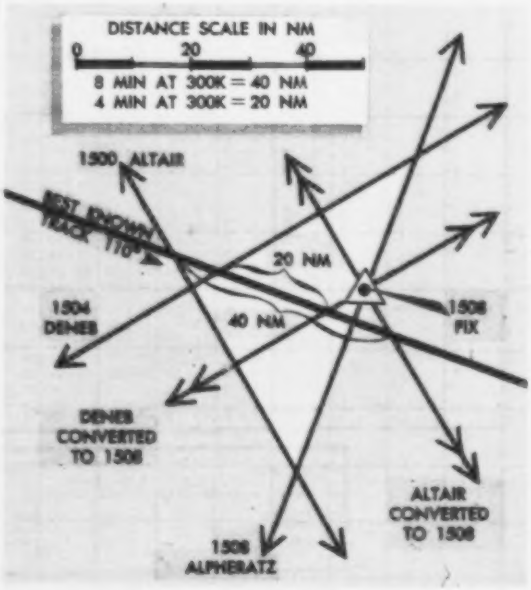
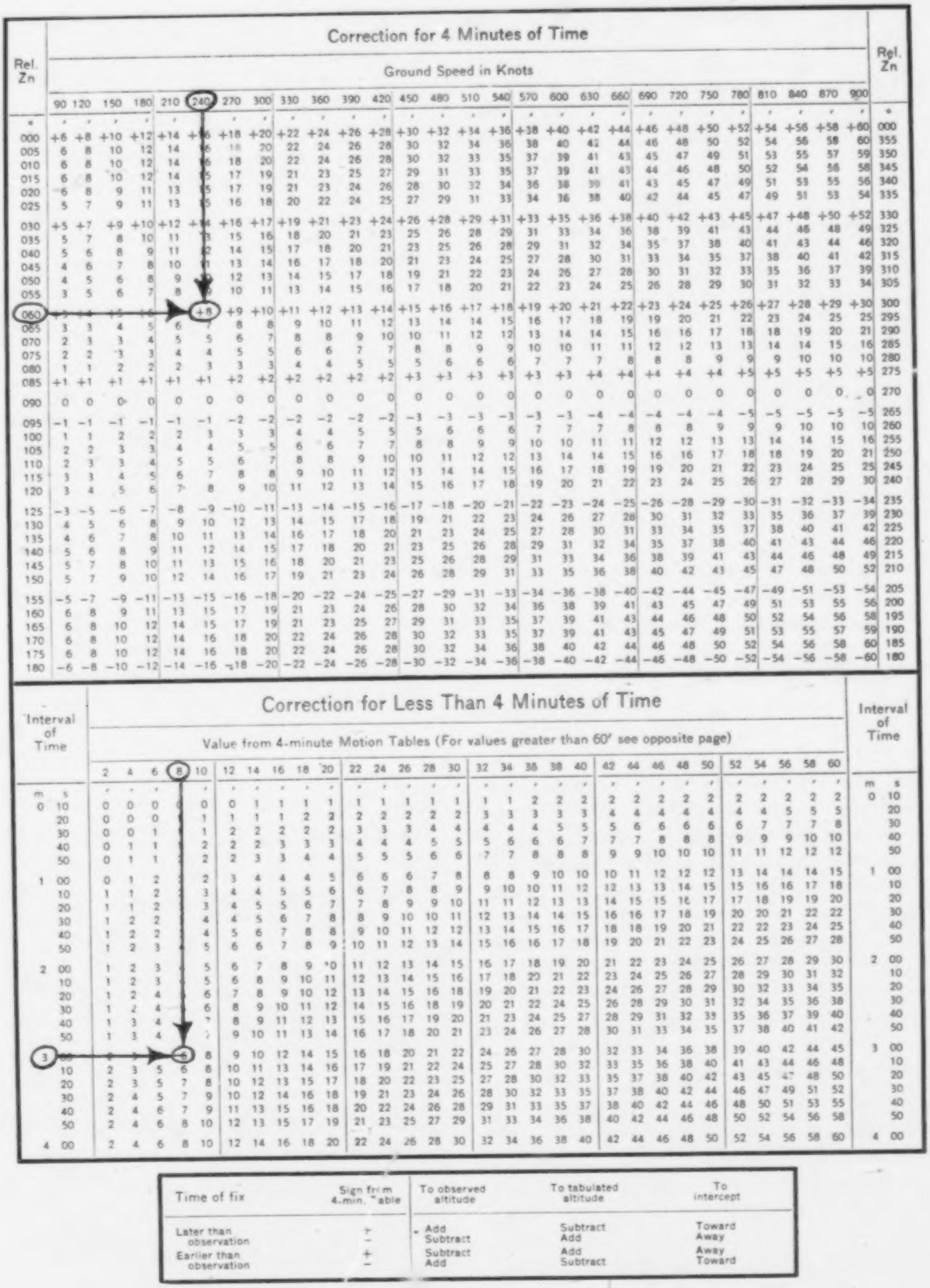


Figure 14-9. Conversion of LOPs to a Common Time



Correction for 4 Minutes of Time

Rel. Zn	90	120	150	180	210	240	270	300	330	360	390	420	450	480	510	540	570	600	630	660	690	720	750	780	810	840	870	900	Rel. Zn
°	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	°
000	+6	+8	+10	+12	+14	+16	+18	+20	+22	+24	+26	+28	+30	+32	+34	+36	+38	+40	+42	+44	+46	+48	+50	+52	+54	+56	+58	+60	000
005	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	355
010	6	8	10	12	14	16	18	20	22	24	26	28	30	32	33	35	37	39	41	43	45	47	49	51	53	55	57	59	350
015	6	8	10	12	14	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	44	46	48	50	52	54	56	58	345
020	6	8	9	11	13	15	17	19	21	23	24	26	28	30	32	34	36	38	39	41	43	45	47	49	51	53	55	56	340
025	5	7	9	11	13	15	16	18	20	22	24	25	27	29	31	33	34	36	38	40	42	44	45	47	49	51	53	54	335
030	+5	+7	+9	+10	+12	+14	+16	+17	+19	+21	+23	+24	+26	+28	+29	+31	+33	+35	+36	+38	+40	+42	+43	+45	+47	+48	+50	+52	330
035	5	7	8	10	11	13	15	16	18	20	21	23	25	26	28	29	31	33	34	36	38	39	41	43	44	46	48	49	325
040	5	6	8	9	11	12	14	15	17	18	20	21	23	25	26	28	29	31	32	34	35	37	38	40	41	43	44	46	320
045	4	6	7	8	10	11	13	14	16	17	18	20	21	23	24	25	27	28	30	31	33	34	35	37	38	40	41	42	315
050	4	5	6	8	9	10	12	13	14	15	17	18	19	21	22	23	24	26	27	28	30	31	32	33	35	36	37	39	310
055	3	5	6	7	8	9	10	11	13	14	15	16	17	18	20	21	22	23	24	25	26	28	29	30	31	32	33	34	305
060	+3	+4	+5	+6	[illegible]	+8	+9	+10	+11	+12	+13	+14	+15	+16	+17	+18	+19	+20	+21	+22	+23	+24	+25	+26	+27	+28	+29	+30	300
065	3	3	4	5	6	7	8	8	9	10	11	12	13	14	14	15	16	17	18	19	19	20	21	22	23	24	25	25	295
070	2	3	3	4	5	5	6	7	8	8	9	10	10	11	12	12	13	14	14	15	16	16	17	18	18	19	20	21	290
075	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	16	285
080	1	1	2	2	2	3	3	3	4	4	5	5	5	6	6	6	7	7	7	8	8	8	9	9	9	10	10	10	280
085	+1	+1	+1	+1	+1	+1	+2	+2	+2	+2	+2	+2	+3	+3	+3	+3	+3	+3	+4	+4	+4	+4	+4	+5	+5	+5	+5	+5	275
090	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	270
095	−1	−1	−1	−1	−1	−1	−2	−2	−2	−2	−2	−2	−3	−3	−3	−3	−3	−3	−4	−4	−4	−4	−4	−5	−5	−5	−5	−5	265
100	1	1	2	2	2	3	3	3	4	4	5	5	5	6	6	6	7	7	7	8	8	8	9	9	9	10	10	10	260
105	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	16	255
110	2	3	3	4	5	5	6	7	8	8	9	10	10	11	12	12	13	14	14	15	16	16	17	18	18	19	20	21	250
115	3	3	4	5	6	7	8	8	9	10	11	12	13	14	14	15	16	17	18	19	19	20	21	22	23	24	25	25	245
120	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	240
125	−3	−5	−6	−7	−8	−9	−10	−11	−13	−14	−15	−16	−17	−18	−20	−21	−22	−23	−24	−25	−26	−28	−29	−30	−31	−32	−33	−34	235
130	4	5	6	8	9	10	12	13	14	15	17	18	19	21	22	23	24	26	27	28	30	31	32	33	35	36	37	39	230
135	4	6	7	8	10	11	13	14	16	17	18	20	21	23	24	25	27	28	30	31	33	34	35	37	38	40	41	42	225
140	5	6	8	9	11	12	14	15	17	18	20	21	23	25	26	28	29	31	32	34	35	37	38	40	41	43	44	46	220
145	5	7	8	10	11	13	15	16	18	20	21	23	25	26	28	29	31	33	34	36	38	39	41	43	44	46	48	49	215
150	5	7	9	10	12	14	16	17	19	21	23	24	26	28	29	31	33	35	36	38	40	42	43	45	47	48	50	52	210
155	−5	−7	−9	−11	−13	−15	−16	−18	−20	−22	−24	−25	−27	−29	−31	−33	−34	−36	−38	−40	−42	−44	−45	−47	−49	−51	−53	−54	205
160	6	8	9	11	13	15	17	19	21	23	24	26	28	30	32	34	36	38	39	41	43	45	47	49	51	53	55	56	200
165	6	8	10	12	14	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	44	46	48	50	52	54	56	58	195
170	6	8	10	12	14	16	18	20	22	24	26	28	30	32	33	35	37	39	41	43	45	47	49	51	53	55	57	59	190
175	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	185
180	−6	−8	−10	−12	−14	−16	−18	−20	−22	−24	−26	−28	−30	−32	−34	−36	−38	−40	−42	−44	−46	−48	−50	−52	−54	−56	−58	−60	180

Ground Speed in Knots

Correction for Less Than 4 Minutes of Time

Value from 4-minute Motion Tables (For values greater than 60′ see opposite page)

Interval of Time	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	Interval of Time
m s	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	m s
0 10	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	0 10
20	0	0	0	[illegible]	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4	4	4	5	5	5	20
30	0	0	1	[illegible]	1	2	2	2	2	2	3	3	3	4	4	4	4	4	5	5	5	6	6	6	6	6	7	7	7	8	30
40	0	1	1	[illegible]	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6	7	7	7	8	8	8	9	9	9	10	10	40
50	0	1	1	[illegible]	2	2	3	3	4	4	5	5	5	6	6	7	7	8	8	8	9	9	10	10	10	11	11	12	12	12	50
1 00	0	1	2	[illegible]	2	3	4	4	4	5	6	6	6	7	8	8	8	9	10	10	10	11	12	12	12	13	14	14	14	15	1 00
10	1	1	2	[illegible]	3	4	4	5	5	6	6	7	8	8	9	9	10	10	11	12	12	13	13	14	15	15	16	16	17	18	10
20	1	1	2	[illegible]	3	4	5	5	6	7	7	8	9	9	10	11	11	12	13	13	14	15	15	16	17	17	18	19	19	20	20
30	1	2	2	[illegible]	4	4	5	6	7	8	8	9	10	10	11	12	13	14	14	15	16	16	17	18	19	20	20	21	22	22	30
40	1	2	2	[illegible]	4	5	6	7	8	8	9	10	11	12	12	13	14	15	16	17	18	18	19	20	21	22	22	23	24	25	40
50	1	2	3	[illegible]	5	6	6	7	8	9	10	11	12	13	14	15	16	16	17	18	19	20	21	22	23	24	25	26	27	28	50
2 00	1	2	3	[illegible]	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	2 00
10	1	2	3	[illegible]	5	6	8	9	10	11	12	13	14	15	16	17	18	20	21	22	23	24	25	26	27	28	29	30	31	32	10
20	1	2	4	[illegible]	6	7	8	9	10	12	13	14	15	16	18	19	20	21	22	23	24	26	27	28	29	30	32	33	34	35	20
30	1	2	4	[illegible]	6	8	9	10	11	12	14	15	16	18	19	20	21	22	24	25	26	28	29	30	31	32	34	35	36	38	30
40	1	3	4	[illegible]	7	8	9	11	12	13	15	16	17	19	20	21	23	24	25	27	28	29	31	32	33	35	36	37	39	40	40
50	1	3	4	[illegible]	7	9	10	11	13	14	16	17	18	20	21	23	24	26	27	28	30	31	33	34	35	37	38	40	41	42	50
3 00	2	3	[illegible]	6	8	9	10	12	14	15	16	18	20	21	22	24	26	27	28	30	32	33	34	36	38	39	40	42	44	45	3 00
10	2	3	5	6	8	10	11	13	14	16	17	19	21	22	24	25	27	28	30	32	33	35	36	38	40	41	43	44	46	48	10
20	2	3	5	7	8	10	12	13	15	17	18	20	22	23	25	27	28	30	32	33	35	37	38	40	42	43	45	47	48	50	20
30	2	4	5	7	9	10	12	14	16	18	19	21	23	24	26	28	30	32	33	35	37	38	40	42	44	46	47	49	51	52	30
40	2	4	6	7	9	11	13	15	16	18	20	22	24	26	28	29	31	33	35	37	38	40	42	44	46	48	50	51	53	55	40
50	2	4	6	8	10	12	13	15	17	19	21	23	25	27	29	31	33	34	36	38	40	42	44	46	48	50	52	54	56	58	50
4 00	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	4 00

Time of fix	Sign from 4-min. table	To observed altitude	To tabulated altitude	To intercept
Later than observation	+ −	Add Subtract	Subtract Add	Toward Away
Earlier than observation	+ −	Subtract Add	Add Subtract	Away Toward

Figure 14-10. Entering Arguments are Relative Zn and GS

last shot is at 1802. Retarding the LOP two minutes of groundspeed on a track of 70° would be the same as advancing it two minutes of groundspeed on a track of 250°.

Motion of Observer Tables. A second method of conversion of LOPs to a common time is with a Motion of the Observer table such as the one in H.O. 249. This table gives a correction to be applied to the Ho or Hc, so that the LOP initially plots in its converted position. The correction obtained from Table 1 in H.O. 249 is for 4 minutes of time. An additional table allows the navigator to get the correction for the number of minutes he needs.

For example, suppose that he needs to advance an LOP for 11 minutes and the Ho of the body is 33°29′ and its Zn 80°. The track of the aircraft is 020° and the groundspeed is 240 knots. In the Table 1, Correction for Motion of the Observer for 4 Minutes of Time, illustrated in figure 14-10, the entering arguments are Rel. Zn and groundspeed in knots. Rel. Zn is azimuth relative to course (Zn minus Track, or Track minus Zn). Because of the mathematics involved, Zn minus Track or Track minus Zn may be used as entering arguments. Merely subtract the smaller angle from the larger and enter the table with the value found. In this case Zn−track=080°−020°=60° (Rel. Zn) and groundspeed is 240 knots. Entering this table with these arguments, the correction listed is +8 for 4 minutes of time.

Therefore, the correction needed to advance the LOP for 11 minutes is +16′ (for 8 minutes), plus the correction needed for the additional 3 minutes which is obtained from the bottom portion of Table 1. Enter this portion of the table with +8 (value for 4 minutes) and 3 minutes. The correction in this case is +6′, thus obtaining a total of +22′.

Hence, the 11-minute correction to be applied to the Ho is +22′. The corrected Ho is now 33°51′. Comparing this new Ho with Hc gives an intercept which places the LOP in its adjusted position.

In the problem above, the +22′ correction to Ho may also be applied to the Hc instead of the Ho by reversing the sign as indicated in the list of rules below Table 1. In this case −22′ would be applied to the tabulated altitude (Hc). As the rules show, the adjustment may also be applied to the intercept. The resultant intercept would be the same.

In the sample problem, suppose the Hc were 33°57′. The intercept is 6 nautical miles away. If the navigator had used the original Ho of 33°29′ and applied −22′ to the Hc, he would have obtained an Hc of 33°35′ and still have an intercept of 6 nautical miles away.

When using the Motion of the Observer Table and when the fix time is earlier than the observation (LOP to be retarded), the rule for the sign of the correction is also printed below Table 1.

Moving Assumed Position. Another method of converting LOPs to a common time is to move the assumed position. This method is recommended for shots four minutes apart computed to give all three bodies a single assumed position. However, it is not limited to that type of computation. The assumed position is moved along the best known track at the best known groundspeed. For example, again suppose that the track is 330° and the groundspeed 300 knots. LOPs are for 1500, 1504, and 1508, and a fix is desired at 1508 (figure 14-11).

Since the first LOP would have to be advanced 40 nautical miles (8 min at 300 k), the same result is realized by advancing the assumed position 40 nautical miles parallel to the best known track. The 1504 LOP must be advanced 20 nautical miles; therefore the assumed position is advanced 20 nautical miles parallel to the best known track. The third shot requires no movement, and it is plotted from the original assumed position. It

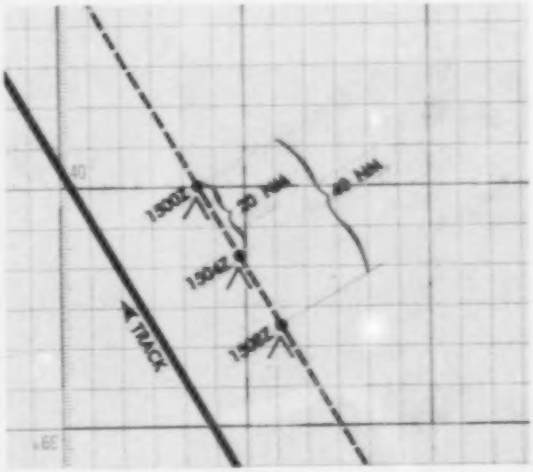


Figure 14-11. Moving Assumed Positions

should be noted that the first shot is always plotted from the assumed position which is closest to destination. In this method, if observations are precomputed and the assumed position is moved prior to shooting, the following procedure is used when shooting is off schedule. For every minute of time that the shot is taken early, move the assumed position 15 minutes of longitude to the east. For every minute of time that the shot is taken late, move the assumed position 15 minutes of longitude to the west.

Planning The Fix. In selecting bodies for observation, one should generally consider azimuth primarily and such factors as brightness, altitude, etc. secondarily. If all observations were precisely correct in every detail, the resulting lines of position would meet at a point. However, this is rarely the case. Three observations generally result in lines of position forming a triangle. If this triangle is not more than two or three miles on a side under good conditions, and five to ten miles under unfavorable conditions, there is normally no reason to suppose that a mistake has been made. Even a point fix, however, is not necessarily accurate. An uncorrected error in *time*, for instance, would move the entire fix eastward if early and westward if late, at the rate of 1 minute of longitude for each 4 seconds of time.

In a two-LOP fix, the ideal cut of the LOPs is 90°. Notice in figure 14-12 that with this cut, a 5-mile error in one LOP will cause a 5-mile error in the fix. If the acute angle between the LOPs is 30°, a 5-mile error in one LOP will cause a 10-mile error in the fix. Thus, with a two-LOP fix, an error in one LOP will cause at least an equal error in the fix; the smaller the acute angle between the LOPs, the greater the fix error caused by a given error in one LOP. Of course, if both LOPs are in error, the fix may be thrown off even more.

In a three-LOP fix, the ideal cut of the LOPs is 60° (star azimuths 120° apart). With this cut, a 3-mile error in any one LOP will cause a 2-mile error in the fix. With any other cut, a 3-mile error in any one LOP will cause more than a 2-mile error in the fix.

In a three-star fix, the cut will be 60° if the azimuths of the stars differ by 60° or if they differ by 120°. If there is any unknown constant error in the observations, all the Ho's will be either too great or too small. Notice in figure 14-13 that, if stars are selected whose azimuths differ by 120°, this constant error of the Ho's will cause a displacement of the three LOPs, either all toward the center or all away from the center of the triangle. In either case, the position of the center of the triangle will not be affected. Similarly, if the navigator uses any three stars, the azimuths of which do not fall within 180°, any constant error in observations will tend to cancel out.

The three-star fix has two distinct advantages over the two-star fix. First, it is the average of three observations. Second, the effect of constant errors of observation can be counteracted by selecting the stars carefully. There is also a third advantage. Each pair of two LOPs furnishes a rough check on the third. In resolving an observation into an LOP, the navigator might possibly make a gross error; for example, he might obtain

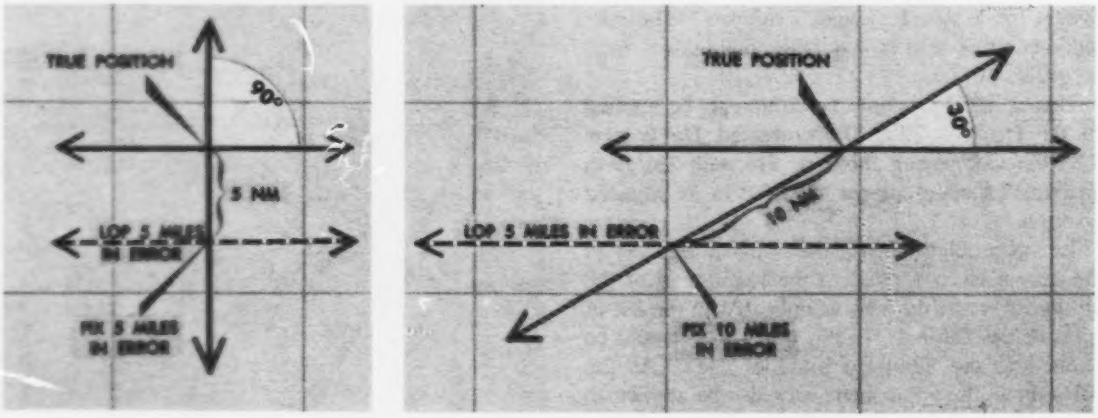
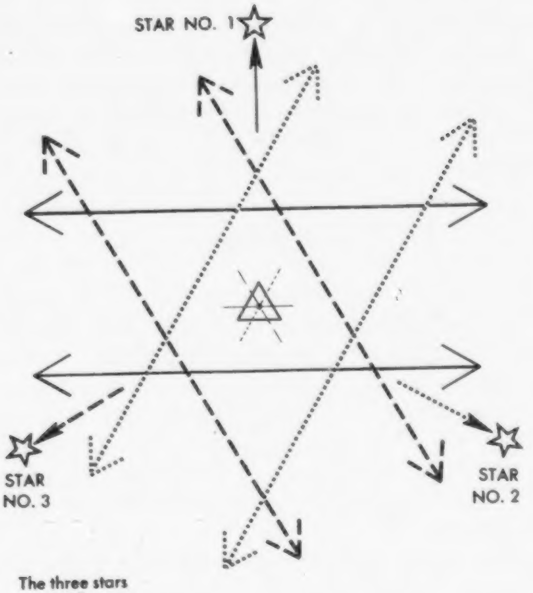


Figure 14-12. Effect of Cut on Accuracy of Fix



The three stars are 120° apart.

Figure 14-13. Effect of Azimuth on Accuracy of Fix

an LHA which is in error by a whole degree. Such an error might not be immediately apparent. Neither would such a discrepancy come to immediate attention in a two-LOP fix. However, this third advantage does not apply when a single LHA is used in solving for all LOPs, such as is done when precomputing and using motion corrections to resolve all LOPs to a common time. Because of these three advantages, it is evident that a three-star fix should be used, rather than a two-star fix, whenever possible.

Whatever the number of observations, common practice, backed by logic, is to take the center of the figure formed unless there is reason for deviating from this procedure. By "center" is meant the point representing the least total error of all lines considered reliable. With three lines of position, the center is considered that point, within the triangle, which is equidistant from the three sides. It may be found by bisecting the angles, but more commonly it is located by eye.

Effect of Fix Error. In determining track and groundspeed from departure to a fix, the greater the distance, the less the relative effect of a given fix error, and the more accurate the track and groundspeed determination. The same is true in determining track and groundspeed between fixes. However, when two points are subject to error, the track and groundspeed between them are twice as liable to error as when one point is definitely known.

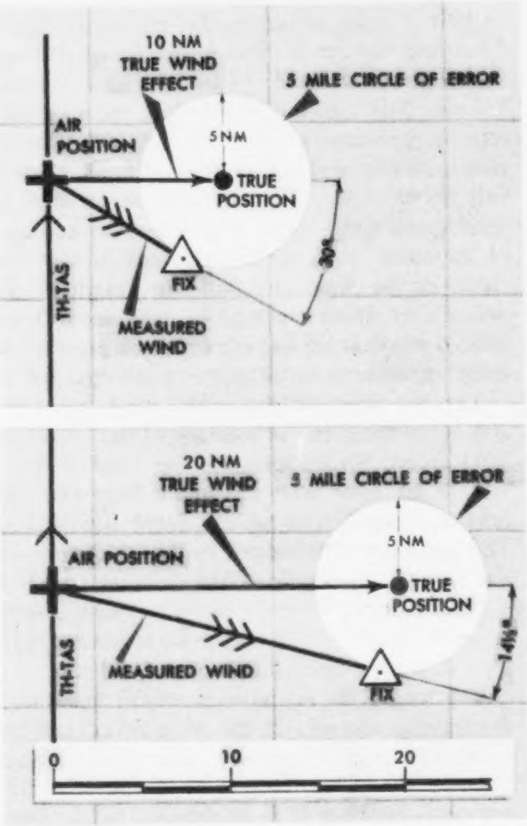


Figure 14-14. The Greater the Wind Effect, the Smaller the Error

In map reading, a fix is relatively accurate; therefore, the chief source of error in the calculated wind is inaccuracy in the true heading and true airspeed. When using celestial means or the radio, fixes often are less accurate than are air positions. Since the fix and the air position may both be in error, the wind determined from them may be quite inaccurate. Consequently, the use of radio and celestial fixes requires better judgment than does the use of map reading fixes.

The magnitude of the error in a calculated average wind varies with the error of the fix and with the error of the air position. It varies also with the magnitude of the wind effect and with the length of the period over which the wind is being determined.

With a given fix error, the greater the wind effect, the less the error in measured wind direction as shown in figure 14-14. The fix is 5 miles in error. With a 10-mile wind effect, the maximum error in measured wind direction is 30°; whereas with a 20-mile wind effect, the maximum error is only about 14½°. Wind effect is proportional to wind speed and to time. Therefore, the accuracy of measured wind direction increases with the speed of the wind and with the length of the period over which the wind is determined. If the wind is weak, small fix errors may be expected to cause apparent inconsistency of wind direction.

The magnitude of the actual wind speed has almost no effect on the accuracy of the calculated wind speed. No matter what the wind speed, a 10-mile fix error after an hour's flight can give only a 10-knot error in calculated wind speed. The navigator is interested in the absolute error and not the percentage error in wind speed. A 10-knot absolute error always will cause a 10-mile position error after an hour; this is true whether the true wind speed is one knot or 100 knots.

The longer the period over which the wind is determined, the greater the wind effect, and the smaller the relative influence of a given fix error upon the wind effect. Hence, the longer the period, the more accurate the value obtained for the speed of the average wind. Doubling the time also doubles the wind effect, and hence, will halve the maximum error in calculated wind speed caused by a given fix error.

The examples have been given in terms of airplot, but the conclusions are valid however the wind is found. It has been assumed in the examples that there was no error in air positions. However, DR errors are cumulative; whereas, the error of a fix is not affected by distance from departure. When the cumulative error of the airplot has become greater than the average fix error, then results can be improved by restarting the airplot from a fix. The difficulty is to recognize that time when it comes.

SUMMARY

Because of all the factors involved, a certain amount of judgment is necessary, along with the proper use of the mechanics comprising celestial navigation. When using a single LOP or a fix, the navigator has to take into consideration the existing conditions and weigh the DR information against the information obtained from the LOP.

An accurate DR position should always be computed.

A formula has been devised to aid in determining an MPP from a single LOP, but the navigator may want to make further adjustments to the final position. The formula is

$$\frac{d}{t} = \frac{p}{t+p}$$

Remember, *d* is the distance measured along a perpendicular from the DR position to the LOP.

In the case of the two- or three-star fix, planning plays a very important part. Selecting stars whose azimuths differ by 120° for a three-star fix will minimize errors in the fix position. In two-star fixes, the ideal azimuth separation is 90°. Also, when dealing with more than one LOP, it is necessary to resolve the LOPs to a common time. This adjustment can be accomplished by moving the assumed position, by moving the LOPs, or by applying a correction factor to the Hc or Ho.

CHAPTER 15

Sextants and Errors of Observation

A celestial LOP is determined by measuring the altitude of a celestial body with a sextant. The sextants now in general use are of two types: (1) marine sextants, which measure altitude above the visible horizon, and (2) aircraft bubble sextants, which measure altitude above the artificial horizon; that is, above the celestial horizon as established by a leveling device (the bubble). The marine sextant is not used for aerial navigation and, consequently, is not discussed in this manual.

Sextants are subject to certain errors that must be compensated for when determining LOPs. Some of these errors are corrected by adjusting the Hs or Hc, and others are corrected by adjusting the LOP or assumed position. Most of the material presented in this chapter is devoted to the explanation of the causes of these errors and the necessary corrections.

THE BUBBLE SEXTANT

The aircraft bubble sextant measures altitude above a horizontal plane established by a bubble. The Air Force uses several types of bubble sextants, all of which are indirect sighting. This means the navigator does not look directly toward the celestial body, but always looks in a horizontal direction as shown in figure 15-1. The image of the body is reflected into the field of view when the field prism is set at the correct angle. In the bubble sextant, the bubble and body are visible in the same field of view.

Accurate observations can be obtained from the various bubble sextants by using proper collimation techniques, and by using the proper size bubble. Collimation is effected when the body is placed in the center of the bubble.

For greatest accuracy, the bubble should be in the center of the field. The error will be small if the bubble is anywhere on the vertical line of the field, as long as it does not touch the top or bottom of the bubble chamber. Figure 15-2 shows examples of correct and incorrect collimation.

Bubble size affects the accuracy of a sextant observation. The ideal situation is to have a small bubble for ease in determining the center. However, too small a bubble is sluggish, and it is better to have a bubble that is active. Experience has shown that best results can be obtained with a bubble approximately one and a half times the apparent diameter of the sun or moon.

The field prism is geared to an altitude scale so that when the body is collimated the altitude can be read from the scale. An averaging mechanism is also incorporated which allows the navigator to take a series of observations over a period of time. This is more accurate than relying on a single observation.

ERRORS OF SEXTANT OBSERVATION

If collimation of the body with the bubble and reading the sextant were all that had to be done, celestial navigation would be simple. This would mean that LOPs accurate to within one or two miles could be abtained without any further effort. Unfortunately, considerable errors are encountered in every sextant observation made from an aircraft. A thorough understanding of the cause and magnitude of these errors, as well as the proper application of corrections to either the Hc or Hs, will help minimize their effect. (Any correction applied to the Hs may be applied instead to the

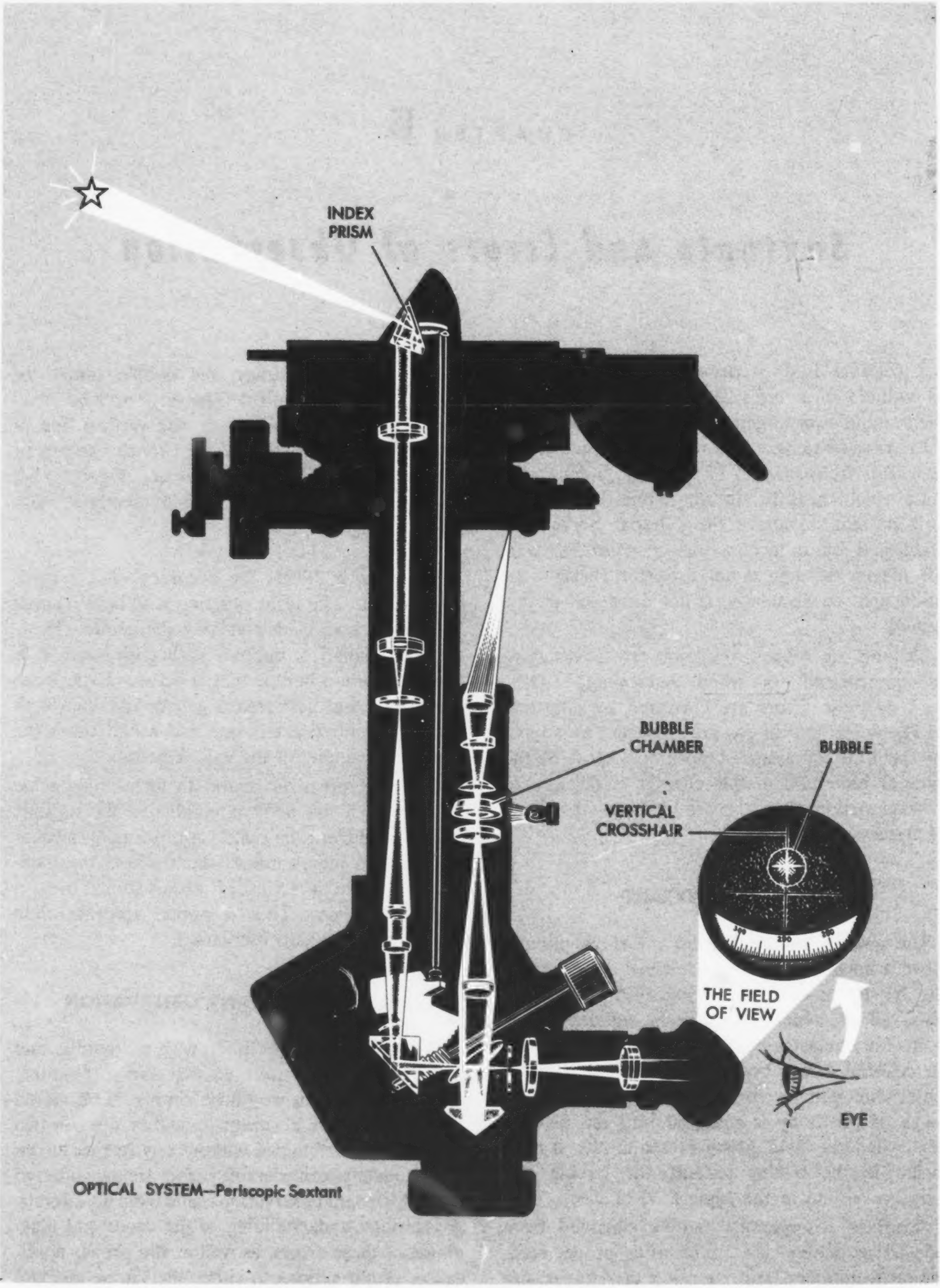

INDEX PRISM
BUBBLE CHAMBER
BUBBLE
VERTICAL CROSSHAIR
THE FIELD OF VIEW
EYE
OPTICAL SYSTEM—Periscopic Sextant

Figure 15-1. Body is Not Sighted Directly

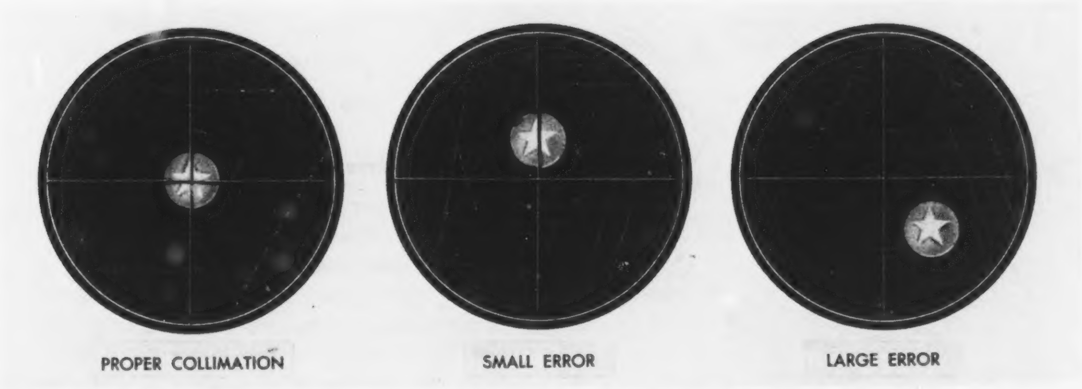


Figure 15-2. Correct and Incorrect Collimation

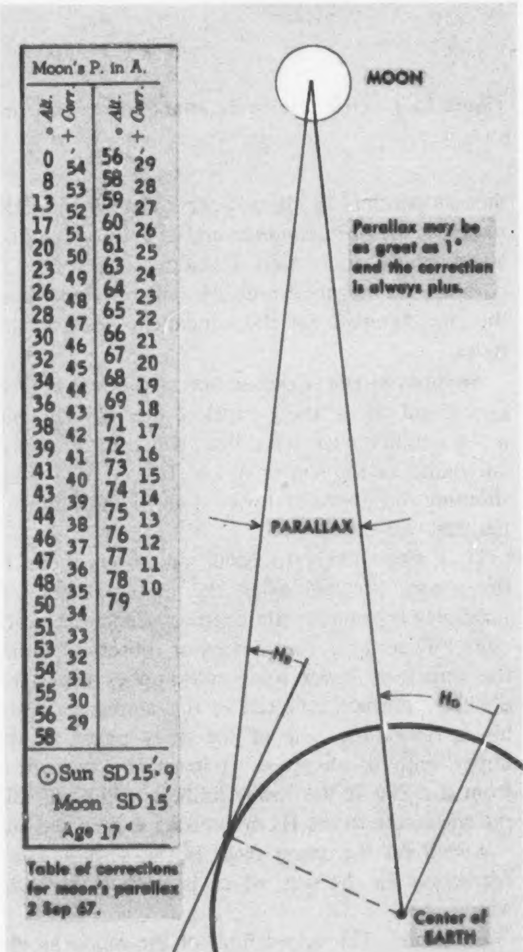
Hc with a reverse sign.) Accuracy of celestial navigation, therefore, depends upon thorough application of these corrections, together with proper shooting techniques.

The errors of sextant observation may be classified into four groups: (1) parallax error, (2) refraction errors, (3) instrument errors, and (4) acceleration errors.

Parallax Error

Parallax in altitude is the difference between the altitude of a body above a bubble horizon at the surface of the earth, and its calculated altitude above the celestial horizon at the center of the earth. All Hc's are given for the center of the earth. If the light rays reaching the earth from a celestial body are parallel, the body has the same altitude at both the center and the surface of the earth. For most celestial bodies, therefore, parallax is negligible for purposes of navigation.

CORRECTION FOR THE MOON. This does not apply to the moon because it is so close to the earth that its light rays are not parallel. The parallax of the moon may be as great as 1°; thus, when observing the moon, a parallax correction must be applied to the Hs. Figure 15-3 shows that the moon appears at a lower altitude from the surface of the earth than it would appear from the center of the earth; therefore, the correction is always plus. The amount of this correction varies with the altitude and with the distance of the moon from the earth. The correction varies from day to day because the distance of the moon from the earth varies. Corrections for the


MOON
Parallax may be as great as 1° and the correction is always plus.
PARALLAX
Hs
Ho
Center of EARTH

Moon's P. in A.

° Alt.	' Corr. +	° Alt.	' Corr. +
0	54	56	29
8	53	58	28
13	52	59	27
17	51	60	26
20	50	61	25
23	49	63	24
26	48	64	23
28	47	65	22
30	46	66	21
32	45	67	20
34	44	68	19
36	43	69	18
38	42	71	17
39	41	72	16
41	40	73	15
43	39	74	14
44	38	75	13
46	37	76	12
47	36	77	11
48	35	78	10
50	34	79	
51	33		
53	32		
54	31		
55	30		
56	29		
58			

☉Sun SD 15'.9
Moon SD 15'
Age 17ᵈ

Table of corrections for moon's parallax 2 Sep 67.

Figure 15-3. Correction for Moon's Parallax

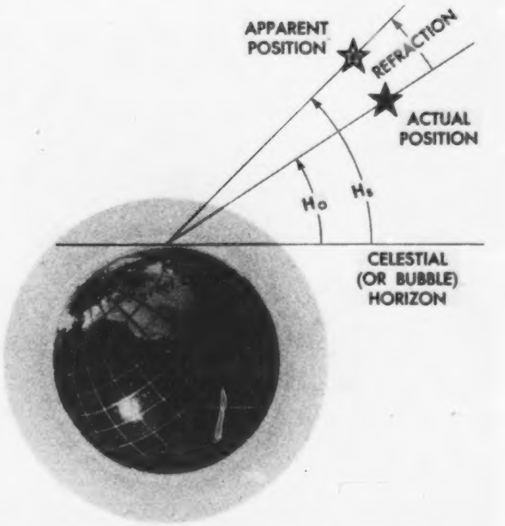


Figure 15-4. Error Caused by Atmospheric Refraction

moon's parallax in altitude are given on the daily pages of the *Air Almanac* and are always added, algebraically, to sextant altitudes. The values of parallax for negative altitudes are obtained from the *Air Almanac* for the equivalent positive altitudes.

SEMIDIAMETER CORRECTION. Another correction found on the daily pages of the *Air Almanac* is the semidiameter correction, which is the apparent radius of the sun or moon. It is needed when shooting the upper or lower limb of the moon or the sun.

It is more likely to occur on observations of the moon, because when the moon is not full (completely round), the center is difficult to estimate. Therefore, the navigator observes either the upper or lower limb and applies the semidiameter correction listed in the almanac on the lower right-hand side of the daily pages. If the upper limb is observed, subtract the correction from the Hs; if the lower limb is observed, add the correction to the Hs or subtract it from the Hc.

Listed on the same page is the semidiameter correction for the sun, which is applied the same way if used.

Example. The upper limb of the moon as observed on 2 Sep 1966 at 30,000 feet is 33°41′. Apply these corrections as:

Hs	33°41′
Parallax	+45′
Semidiameter	−15′
Ho	34°11′

Refraction Errors

Still another factor to be taken into consideration is refraction. If a fishing pole is partly submerged under water, it appears to bend at the surface. This appearance is caused by the bending of light rays as they pass from the water into the air. This bending of the light rays, as they pass from one medium into another, is called *refraction*. The refraction of light from a celestial body, as it passes through the atmosphere causes an error in sextant observation.

ATMOSPHERIC REFRACTION. As the light of a celestial body passes from the almost perfect vacuum of outer space into the atmosphere, it is refracted as shown in figure 15-4 so that the body appears a little higher above the horizon than it really is. Therefore, the correction to the Hs for refraction is always minus. The higher the body above the horizon, the smaller the amount of refraction and, consequently, the smaller the refraction correction. Moreover, the greater the altitude of the aircraft, the less dense the layer of atmosphere between the body and the observer, hence, the less the refraction.

The appropriate correction table for atmospheric refraction is listed inside the back cover of all four books used for celestial computations, namely the *Air Almanac,* and each of the three volumes of H.O. 249. This table, shown in figure 15-5, lists the refraction for different observed altitudes of the body and for different heights of the observer above sea level. The values shown are subtracted from Hs or added to Hc.

Instrument Errors

Certain errors of observation are a result of mechanical faults in the sextant. An aircraft sextant is a delicate instrument which can easily get out of alignment.

INDEX ERRORS. Hard knocks or jars can change the alignment of the index and field prism, thereby causing index error. Some sextants have index errors posted on the sextant or on the sextant case.

TABLE 5.—Refraction

To be subtracted from sextant altitude

R_0	Height above sea level in thousands of feet												R_0	$R=R_0\times f$					
	0	5	10	15	20	25	30	35	40	45	50	55							
	Sextant Altitude													0.8	0.9	1.0	1.1	1.2	1.3
′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	′	′	′	′	′	′	′
	90	90	90	90	90	90	90	90	90	90	90	90							
0													0	0	0	0	0	0	0
	63	59	55	51	46	41	36	31	26	20	17	13							
1													1	1	1	1	1	1	1
	33	29	26	22	19	16	14	11	9	7	6	4							
2													2	2	2	2	2	2	3
	21	19	16	14	12	10	8	7	5	4	2 40	1 40							
3													3	2	3	3	3	4	4
	16	14	12	10	8	7	6	5	3 10	2 20	1 30	0 40							
4													4	3	4	4	4	5	5
	12	11	9	8	7	5	4	3 10	2 10	1 30	0 39	+0 05							
5													5	4	5	5	5	6	6
	10	9	7	5 50	4 50	3 50	3 10	2 20	1 30	0 49	+0 11	−0 19							
6													6	5	5	6	7	7	8
	8 10	6 50	5 50	4 50	4 00	3 00	2 20	1 50	1 10	0 24	−0 11	−0 38							
7													7	6	6	7	8	8	9
	6 50	5 50	5 00	4 00	3 10	2 30	1 50	1 20	0 38	+0 04	−0 28	−0 54							
8													8	6	7	8	9	10	10
	6 00	5 10	4 10	3 20	2 40	2 00	1 30	1 00	0 19	−0 13	−0 42	−1 08							
9													9	7	8	9	10	11	12
	5 20	4 30	3 40	2 50	2 10	1 40	1 10	0 35	+0 03	−0 27	−0 53	−1 18							
10													10	8	9	10	11	12	13
	4 30	3 40	2 50	2 20	1 40	1 10	0 37	+0 11	−0 16	−0 43	−1 08	−1 31							
12													12	10	11	12	13	14	15
	3 30	2 50	2 10	1 40	1 10	0 34	+0 09	−0 14	−0 37	−1 00	−1 23	−1 44							
14													14	11	13	14	15	17	18
	2 50	2 10	1 40	1 10	0 37	+0 10	−0 13	−0 34	−0 53	−1 14	−1 35	−1 56							
16													16	13	14	16	18	19	21
	2 20	1 40	1 20	0 43	+0 15	−0 08	−0 31	−0 52	−1 08	−1 27	−1 46	−2 05							
18													18	14	16	18	20	22	23
	1 50	1 20	0 49	+0 23	−0 02	−0 26	−0 46	−1 06	−1 22	−1 39	−1 57	−2 14							
20													20	16	18	20	22	24	26
	1 12	0 44	+0 19	−0 06	−0 28	−0 48	−1 09	−1 27	−1 42	−1 58	−2 14	−2 30							
25													25	20	22	25	28	30	32
	0 34	+0 10	−0 13	−0 36	−0 55	−1 14	−1 32	−1 51	−2 06	−2 21	−2 34	−2 49							
30													30	24	27	30	33	36	39
	+0 06	−0 16	−0 37	−0 59	−1 17	−1 33	−1 51	−2 07	−2 23	−2 37	−2 51	−3 04							
35													35	28	31	35	38	42	45
	−0 18	−0 37	−0 58	−1 16	−1 34	−1 49	−2 06	−2 22	−2 35	−2 49	−3 03	−3 16							
40													40	32	36	40	44	48	52
		−0 53	−1 14	−1 31	−1 47	−2 03	−2 18	−2 33	−2 47	−2 59	−3 13	−3 25							
45													45	36	40	45	50	54	58
		−1 10	−1 28	−1 44	−1 59	−2 15	−2 28	−2 43	−2 56	−3 08	−3 22	−3 33							
50													50	40	45	50	55	60	65
			−1 40	−1 53	−2 09	−2 24	−2 38	−2 52	−3 04	−3 17	−3 29	−3 41							
55													55	44	49	55	60	66	71
				−2 03	−2 18	−2 33	−2 46	−3 01	−3 12	−3 25	−3 37	−3 48							
60													60	48	54	60	66	72	78
							−2 53	−3 07	−3 19	−3 31	−3 42	−3 53							
65													65	52	58	65	72	78	84
														0.8	0.9	1.0	1.1	1.2	1.3

f	Height above sea level in thousands of feet												f	Refraction $R=R_0\times f$
	0	5	10	15	20	25	30	35	40	45	50	55		
	Temperature in degrees Celsius (centigrade)													
0.8													0.8	When R_0 is less than 10′ or the height is greater than 35,000 ft. take $f=1.0$ and use $R=R_0$.
	+47	+36	+27	+18	+10	+ 3	− 5	−13	For these heights no temperature correction is necessary: take $f=1.0$ and use $R=R_0$.					
0.9													0.9	
	+26	+16	+ 6	− 4	−13	−22	−31	−40						
1.0													1.0	
	+ 5	− 5	−15	−25	−36	−46	−57	−68						
1.1													1.1	
	−16	−25	−36	−46	−58	−71	−83	−95						
1.2													1.2	
	−37	−45	−56	−67	−81	−95								
1.3													1.3	

Choose the column appropriate to height, in units of 1,000 feet, and find the range of altitude in which the sextant altitude lies; thus find R_0. This is the refraction corresponding to the sextant altitude unless conditions are extreme. In that case find f from the lower table corresponding to the range of temperature for the appropriate height, and use the table on the right to find R. Example: at a height of 30,000 feet and temperature (−) 60° C a celestial body is observed at altitude (−) 2°36′. R_0 is 50′, f is 1.1, and R is 55′. Subtracting this from the sextant altitude gives (−) 3°31′.

Figure 15-5. Corrections for Atmospheric Refraction

Index error is usually the largest mechanical error in the sextant. This error is caused by improper alignment of the index prism with the altitude counter. No matter how carefully a sextant is handled, it is likely to have some index error. If the error is small, the sextant need not be readjusted; rather, each Hs can be corrected by the amount of the error. This means that the index error of the sextant must be known to obtain an accurate celestial LOP.

BACKLASH. Another mechanical error found in sextants is backlash. This is caused by excessive play in the gear train connecting the index prism to the altitude counter.

Usually these errors are nearly constant through the altitude range of the sextant. Therefore, if the error at one altitude setting is determined, the correction can be applied to any Hs or Hc. The correction is of equal value to the error but of opposite sign. For safety, the sextant should be checked on the ground before every flight during which the navigator expects to rely on celestial observations.

Acceleration Errors

Presently, the only practical and continuously available reference datum for the definition of the true vertical is the direction of the gravitational field of the earth. Definition of this vertical establishes the artificial horizon. It is also fundamental that the forces caused by gravity cannot be separated from those caused by accelerations by any self-contained means within the sextant. A level or centered bubble in the sextant indicates the true vertical only when the instrument is at rest or moving at a constant velocity in a straight line. Any outside force (changes in groundspeed or changes in track) will affect the liquid in the bubble chamber and, consequently, displace the bubble.

When the sextant is moved in a curved path (Coriolis, changes in heading, rhumb line) or with varying speed, the zenith indicated by the bubble is displaced from the true vertical. This presents a false artificial horizon above which the altitude of the celestial body is measured. Since the horizon used is false, the altitude measured from it is erroneous. Therefore, the accuracy of celestial observations is directly related to changes in track and speed of the aircraft. Acceleration errors have two principal causes: changes in groundspeed and curvature of the aircraft's path in space.

The displacement of the liquid and the bubble in the chamber may be divided into two vectors, and each vector may be considered separately. These vectors may be thought of as a lateral vector (along the wings) and a longitudinal vector (along the nose-tail axis of the aircraft). Any change in groundspeed can cause a longitudinal displacement. This change can be brought about by a change in the airspeed or the wind encountered, or the change in groundspeed brought about by a change in heading due to other factors (gyro precession, rhumb line error, etc.). A lateral displacement results from a number of causes, most of which will occur in spite of any efforts to hold them in check. These causes are termed Coriolis, rhumb line error, and wander errors.

CHANGES IN GROUNDSPEED. This error is caused primarily by changes in airspeed or changes in wind velocity. Errors due to changes in groundspeed will normally be small. The computation of the amount of error is based on the assumption that a one-knot error in true airspeed will produce a one-knot error in groundspeed. If this occurs during a one-minute shooting period, it will cause up to three nautical miles of error in the LOP, irrespective of the speed of the aircraft. The maximum error would occur on a speed line shot.

Wind velocity also causes changes in groundspeed but the amount cannot be determined. This change in groundspeed (acceleration-deceleration) will cause the liquid to be displaced, with the subsequent shifting of the bubble creating a false horizon. Notice in figure 15-6 how the horizon is automatically displaced by keeping the bubble in the center while these changes are taking place.

CORIOLIS FORCE. Any freely moving body traveling at a constant speed above the earth is subject to an apparent force which deflects its path to the right in the Northern Hemisphere, and to the left in the Southern Hemisphere. This apparent force and the resulting acceleration were first discovered shortly before the middle of the nineteenth century by Gaspard Gustave de Coriolis (1792-1843) and given quantitative formulation by Ferrel. The acceleration is known as Coriolis acceleration (or force) or simply Coriolis, and is expressed in Ferrel's law.

The navigator must realize that the bubble sextant indicates the true vertical only when the instrument is at rest or moving at a constant speed in a straight line as perceived in space. If the earth were motionless, this straight path in space would also be a straight path over the surface of the earth; conversely, a straight path over the motionless earth would also be a straight path in space.

When the aircraft is flying a path curved in space to the left, the fluid in the bubble chamber is deflected to the right and the bubble is deflected to the left of the aircraft's path over the earth. When the aircraft is flying a curved path in space to the right, the reverse is true.

In figure 15-7, the aircraft is represented as flying on a curved path to the left. Note that in the inset representing the bubble chamber, the heavy black bubble is indicated in its approximate position representing the true vertical.

However, the observer always seeks to center the bubble, and on this beam shot, facing to the right side of the aircraft to observe the body, he would tip the sextant up. This would tilt the bubble horizon from its true position, producing a smaller sextant reading than the true

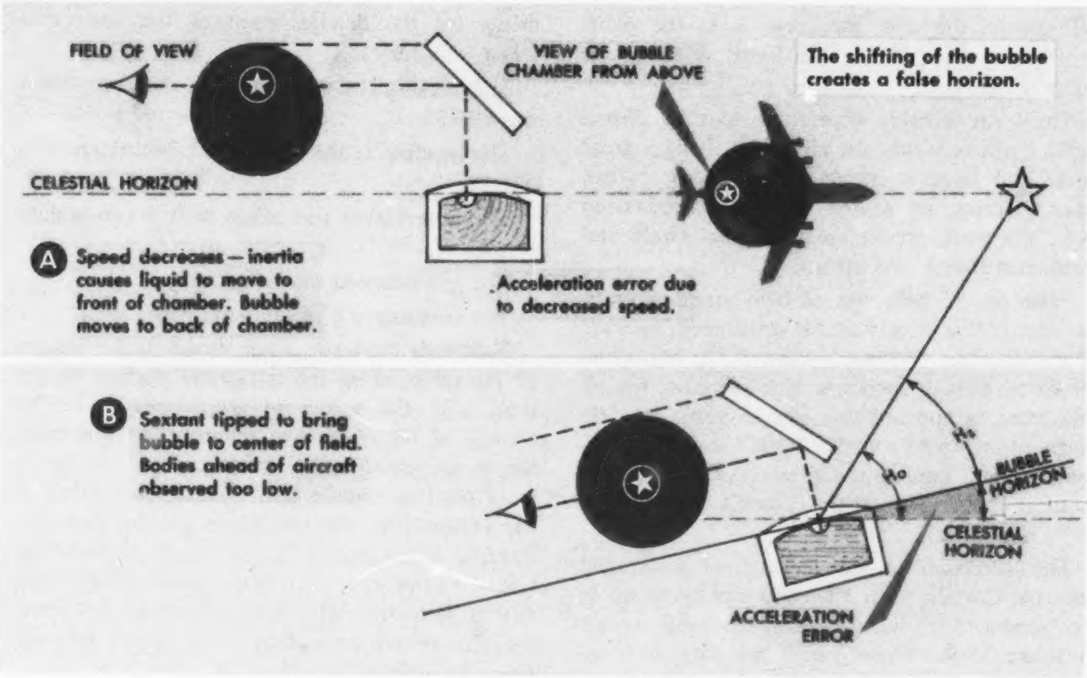

FIELD OF VIEW
VIEW OF BUBBLE CHAMBER FROM ABOVE
The shifting of the bubble creates a false horizon.
CELESTIAL HORIZON
A Speed decreases — inertia causes liquid to move to front of chamber. Bubble moves to back of chamber.
Acceleration error due to decreased speed.
B Sextant tipped to bring bubble to center of field. Bodies ahead of aircraft observed too low.
Ho
Hs
BUBBLE HORIZON
CELESTIAL HORIZON
ACCELERATION ERROR

Figure 15-6. Acceleration/Deceleration Errors

value. Following the rule — the smaller the Ho, the greater the radius of the circle of equal altitude—the LOP will fall farther from the subpoint than the true LOP. Obviously, if the erroneous LOP falls farther from the subpoint, it will fall to the left of the true LOP and the correction to the right is valid. Corrections for Coriolis error are shown on the inside back cover of the almanac as well as in all volumes of H.O. 249.

Coriolis acceleration is:

- Directly proportional to the straight line velocity.
- Directly proportional to the angular velocity of the earth.
- Directly proportional to the sine of the latitude.
- At right angles to the direction of motion of the particle, and therefore it can only influence its direction, never its speed.

Rhumb Line Error. As long as a constant true heading is flown, the path of the aircraft will be a rhumb line. Because a rhumb line on the earth's surface is a loxodromic curve, it is also a curved line in space. If the aircraft is headed in a general easterly direction in the northern hemisphere, the apparent curve is to the left and becomes an addition to the Coriolis error. By the same token, if headed in a westerly direction in the northern

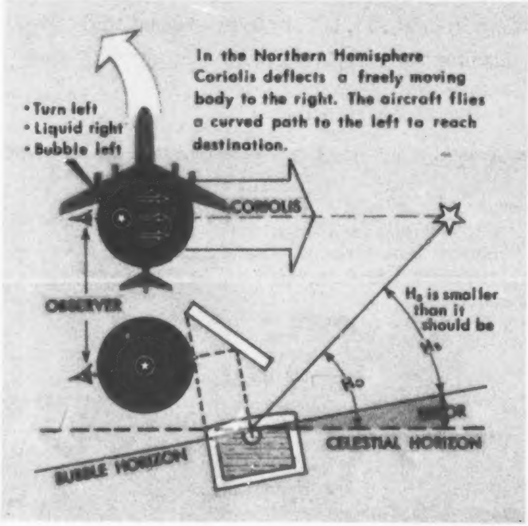

• Turn left
• Liquid right
• Bubble left
In the Northern Hemisphere Coriolis deflects a freely moving body to the right. The aircraft flies a curved path to the left to reach destination.
CORIOLIS
OBSERVER
Hs is smaller than it should be
Hs
Ho
ERROR
CELESTIAL HORIZON
BUBBLE HORIZON

Figure 15-7. Error Caused by Coriolis Force

hemisphere, the apparent curve is to the right, or opposite that of Coriolis force as shown in figure 15-8.

There are notable exceptions to this. When flying north or south, the aircraft is flying a great circle and there is no rhumb line error. Also, when steering by a free running compensated gyro, the track approximates a great circle and eliminates rhumb line error.

Prior to the wide use of high speed aircraft, the rhumb line error was not considered, because at speeds under 300 knots the error is negligible. However, at high speeds or high latitudes, rhumb line error is appreciable. For example, at 60° north latitude with a track of 100° and a groundspeed of 650 knots, the Coriolis correction is 15 nautical miles right and the rhumb line correction is 10 nautical miles right.

The correction for rhumb line error is included with the Coriolis correction and can be found in the combined Coriolis/rhumb line table shown in figure 15-9. These tables are computed for each 50 knots of groundspeed.

WANDER ERROR. A change in track can be produced by changes in the wind velocity, by heading changes between limits of the autopilot, by heading changes produced from changing magnetic variation, and by heading changes derived from pilot manual steering errors. As with the Coriolis force and rhumb line errors, correction tables have been developed for wander error. Values extracted from the wander correction table, shown in figure 15-10, are to be applied to the Ho.

Use the following information as entering arguments for the determination of the correction taken from the table.

The heading at the beginning of the observation was 079.3°.

The heading at the end of the observation was 081.3°.

The observation was taken over a two-minute period.

The groundspeed was 450 knots.

The true azimuth of the body was 130°.

Following the instructions shown at the bottom of the table, enter the numerical portion of the table with the values of groundspeed and the change of track per two minutes. In this case, the groundspeed is 450 knots and the change in track per two minutes is 2°. Since the heading at the end of the observation is greater than the heading at the beginning, the change is 2° to the right. Notice that you must know whether the change is to the right or to the left to determine the sign of the correction. The factor obtained from the table is $12 \times 2 = 24$.

Next, enter the graph portion of the table with the value of the factor (24) and the value of the azimuth of the body minus the value of track. The graph is so constructed that it must be entered with Zn — Tr. In this case, the azimuth is 130° minus a track of 080°; the value thus determined is 050°. Following the rules set down in steps two and three at the bottom of the table, the correction found is 19′. Since the change in track is to the right, the correction is to be subtracted from the Ho. This is determined by referring to the signs shown at the ends of the arc

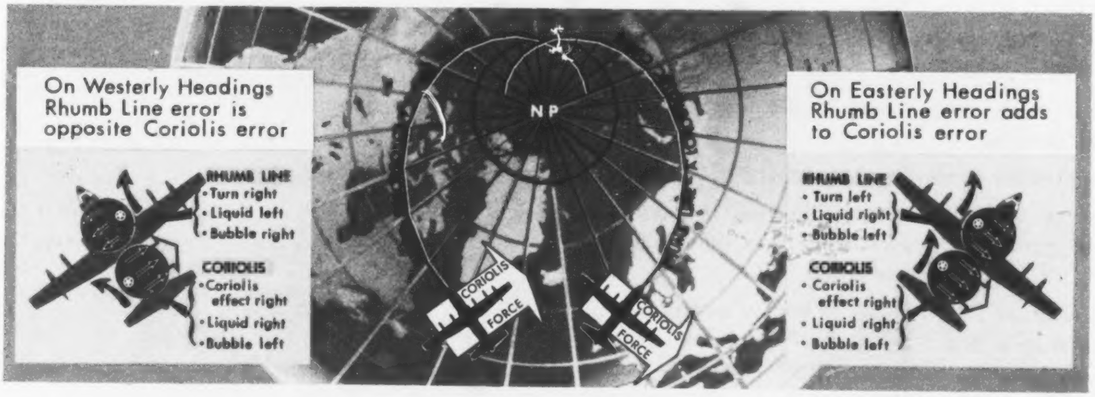

On Westerly Headings Rhumb Line error is opposite Coriolis error
RHUMB LINE
• Turn right
• Liquid left
• Bubble right
CORIOLIS
• Coriolis effect right
• Liquid right
• Bubble left
NP
CORIOLIS FORCE
CORIOLIS FORCE
On Easterly Headings Rhumb Line error adds to Coriolis error
RHUMB LINE
• Turn left
• Liquid right
• Bubble left
CORIOLIS
• Coriolis effect right
• Liquid right
• Bubble left

Figure 15-8. Coriolis/Rhumb Line Errors in Northern Hemisphere

GROUND SPEED 300 KNOTS

TR. → LAT. ↓	270 270	260 280	250 290	240 300	230 310	220 320	210 330	200 340	190 350	180 0	170 10	160 20	150 30	140 40	130 50	120 60	110 70	100 80	90 90
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.4	1.4	1.4	1.5	1.5	1.6	1.6	1.6	1.6	1.6
20	2.2	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.6	2.7	2.8	2.8	2.9	3.0	3.1	3.1	3.1	3.2	3.2
30	3.2	3.2	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.1	4.2	4.3	4.4	4.5	4.6	4.6	4.7	4.7
40	4.0	4.0	4.0	4.1	4.2	4.4	4.5	4.7	4.9	5.1	5.2	5.4	5.6	5.8	5.9	6.0	6.1	6.1	6.2
50	4.5	4.5	4.5	4.7	4.8	5.0	5.2	5.5	5.7	6.0	6.3	6.6	6.8	7.0	7.2	7.4	7.5	7.6	7.6
60	4.6	4.6	4.7	4.9	5.1	5.4	5.7	6.0	6.4	6.8	7.2	7.6	7.9	8.2	8.5	8.8	8.9	9.0	9.0
70	3.8	3.8	4.0	4.3	4.6	5.1	5.6	6.1	6.8	7.4	8.0	8.6	9.2	9.7	10.2	10.5	10.8	10.9	11.0
80	0.3	0.4	0.8	1.3	2.0	3.0	4.0	5.2	6.4	7.7	9.0	10.3	11.5	12.5	13.5	14.2	14.7	15.0	15.1
89	**67.2**	**66.1**	**62.6**	**57.4**	**50.1**	**40.2**	**30.0**	**17.9**	**5.3**	7.9	21.0	33.6	45.7	55.9	65.8	73.1	78.3	81.8	82.9

GROUND SPEED 650 KNOTS

TR. → LAT. ↓	270 270	260 280	250 290	240 300	230 310	220 320	210 330	200 340	190 350	180 0	170 10	160 20	150 30	140 40	130 50	120 60	110 70	100 80	90 90
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1.9	1.9	1.9	2.0	2.1	2.3	2.4	2.6	2.8	3.0	3.1	3.3	3.5	3.7	3.8	3.9	4.0	4.0	4.0
20	3.6	3.6	3.7	3.9	4.1	4.4	4.7	5.1	5.4	5.8	6.2	6.6	7.0	7.3	7.6	7.7	7.9	8.0	8.1
30	5.0	5.0	5.2	5.4	5.8	6.3	6.7	7.3	7.9	8.5	9.1	9.7	10.3	10.8	11.2	11.6	11.8	12.0	12.1
40	5.8	5.9	6.1	6.5	7.0	7.7	8.4	9.2	10.1	11.0	11.8	12.7	13.5	14.2	14.9	15.5	15.8	16.0	16.1
50	5.7	5.8	6.1	6.6	7.4	8.3	9.3	10.5	11.8	13.0	14.3	15.6	16.7	17.7	18.6	19.4	19.9	20.2	20.3
60	4.2	4.3	4.8	5.6	6.6	8.0	9.4	11.1	12.9	14.7	16.5	18.3	20.0	21.5	22.8	23.9	24.6	25.1	25.2
70	**0.9**	**0.6**	0.2	1.3	3.0	5.2	7.5	10.2	13.1	16.0	19.0	21.8	24.5	26.8	29.0	30.7	31.8	32.6	32.9
80	**18.0**	**17.5**	**15.9**	**13.6**	**10.1**	**5.6**	**0.8**	4.8	10.7	16.8	22.8	28.7	34.3	39.1	43.6	47.1	49.4	51.0	51.5
89	**334.8**	**329.2**	**313.0**	**288.9**	**254.5**	**208.2**	**160.1**	**103.6**	**44.6**	17.0	78.7	137.6	194.1	242.2	288.5	322.9	347.0	363.2	368.8

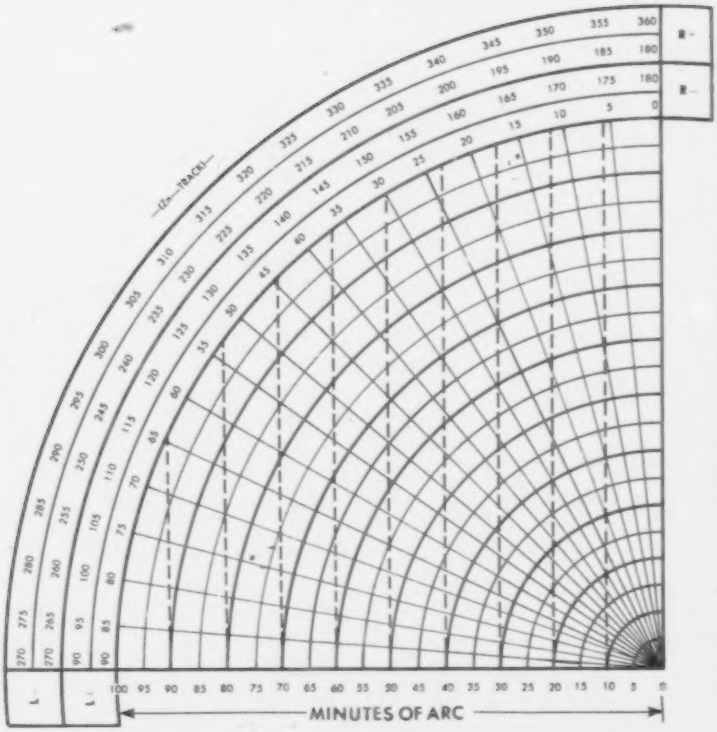
Figures in **BOLD FACE** type are plotted in a direction opposite to that of coriolis force.

*Coriolis corrections alone are the figures in the 0° or 180° column.

Figure 15-9. Combined Coriolis and Rhumb Line Correction

in the table. Figure 15-11 shows the effect of this correction.

If the heading and airspeed are the same at the beginning and the end of a shooting period, there will be no wander error. This is assuming that a change in heading produces an equal change in track, and a change in airspeed produces an equal change in groundspeed. Further, this only applies if the body is continuously collimated during the observation time.



WANDER IN DEGREES PER 2 MINUTES

GROUND SPEED	TRACK CHANGE PER 2 MINUTES .0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
300	0	1'	1.5'	2.5'	3'	4'	5'	5.5'	6.5'	7'	8'
325	0	1	1.5	2.5	3.5	4.5	5	6	7	7.5	8.5
350	0	1	1.5	3	3.5	4.5	5.5	6.5	7.5	8.5	9
375	0	1	2	3	4	5	6	7	8	9	10
400	0	1	2	3	4	5.5	6.5	7.5	8.5	9.5	10.5
425	0	1	2	3.5	4.5	6	7	8	9	10	11.5
450	0	1	2.5	3.5	4.5	6	7	8.5	9.5	10.5	12
475	0	1	2.5	3.5	5	6	7.5	8.5	10	11	12.5
500	0	1.5	2.5	4	5.5	6.5	8	9	10.5	12	13
525	0	1.5	3	4	5.5	7	8.5	9.5	11	12.5	14
550	0	1.5	3	4.5	6	7	8.5	10	11	13	14.5
575	0	1.5	3	4.5	6	7.5	9	10.5	12	13.5	15
600	0	1.5	3	4.5	6.5	8	9.5	11	12.5	14	16
625	0	1.5	3.5	5	6.5	8	10	11.5	13	15	16.5
650	0	1.5	3.5	5	7	9	10.5	12.5	14	15.5	17
675	0	2	3.5	5.5	7	9	10.5	12.5	14	16	17.5
700	0	2	3.5	5.5	7.5	9	11	13	14.5	16.5	18.5
725	0	2	3.5	5.5	7.5	9.5	11.5	13.5	15	17	19
750	0	2	4	6	8	10	12	13.5	15.5	17.5	19.5

INSTRUCTIONS

1. Enter the "Wander in Degrees per 2 Minutes" Table with track change per 2 minutes and groundspeed in knots to obtain the total correction in minutes of arc ( ).
2. Enter the bottom of the graph with the factor just obtained and follow the arc around to intersect the line labeled with the value of Zn-track.
3. Follow the vertical line down from the point obtained in Step 2 to get the correction to Ho with the given sign according to a turn to the left or to the right.

Figure 15-10. Wander Correction Tables

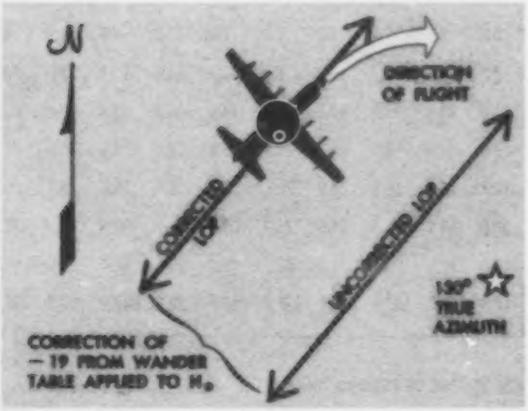


Figure 15-11. Wander Correction Applied to Ho

The amount of force applied over a given time to displace the liquid, and subsequently the bubble, in one direction will be equalized by an amount of force over a given time in the opposite direction to bring the aircraft back to its original heading. Therefore, if the heading (track) and airspeed (groundspeed) are the same at the beginning and end of a shooting, there will be no acceleration error caused by heading or airspeed changes, and no correction is necessary for wander or groundspeed change (a constant wind is assumed over the shooting period).

MINIMIZING ACCELERATION ERRORS. Errors due to acceleration are minimized by the following procedures:

1. Maintain aircraft heading, or desired change of heading, and airspeed as constant as possible (maintenance of track and groundspeed during a shooting period).
2. Average the altitude over a period of time.
3. Apply corrections for known acceleration errors to all observations.

CHAPTER 16

Special Celestial Techniques

There are several special techniques for applying celestial information which can be used under limited conditions. Some save time, and others are valuable for various reasons. Not all of the techniques to be discussed result in an LOP. Some of these are special fixing techniques, others are special celestial procedures to assure arrival over a given destination, and still others are primarily planning techniques.

LATITUDE BY POLARIS

Polaris is the pole star, or North Star. Because Polaris is approximately 1° from the north pole, it makes a small diurnal circle and seemingly stays in about the same place all night. This fact makes Polaris very useful in navigation. With certain corrections, it serves as a reference point for direction and for latitude in the Northern Hemisphere.

Latitude by Polaris is a quick method of obtaining a latitude LOP, and only the tables given in the *Air Almanac* are needed. Many navigators use a Polaris observation in almost every three-star fix. Latitude is found by applying a small "Q" correction to the observed altitude of Polaris.

The correction table appears in the back of the *Air Almanac*. The entering argument is the LHA of Aries, and the Q-correction is extracted. The Q-correction adjusts the altitude of Polaris to the altitude of the pole, which is equal to the navigator's latitude. The Polaris (Pole Star) Table, 1966, is shown in figure 16-1.

Steps in the Polaris Solution

1. Shoot and record the time and Ho of Polaris.
2. Determine the LHA of Aries (to the exact minute of LHA) for the time of the shot.
3. Using the LHA of Aries, enter the Polaris table and extract the value of Q.
4. Algebraically add the value of Q to Ho to get the latitude.
5. Draw a line on the chart at the value of latitude. This line then is the LOP.

Example: On 7 Sep 1966 at 1750 GMT, Polaris was observed at an Hs of 46°59′. The observer's DR position was 47°49′ N-106°52′ W. His flight altitude was 25,000 feet, and flight altitude temperature —35° C. Find the latitude.

Step 1.	Hs	46°59′	
	Refraction	0′	
	Ho	46°59′	for Polaris at 1750 GMT

Step 2.	1750 GHA Aries	253°51′
	Longitude W	—106°52′ W
	LHA Aries	146°59′

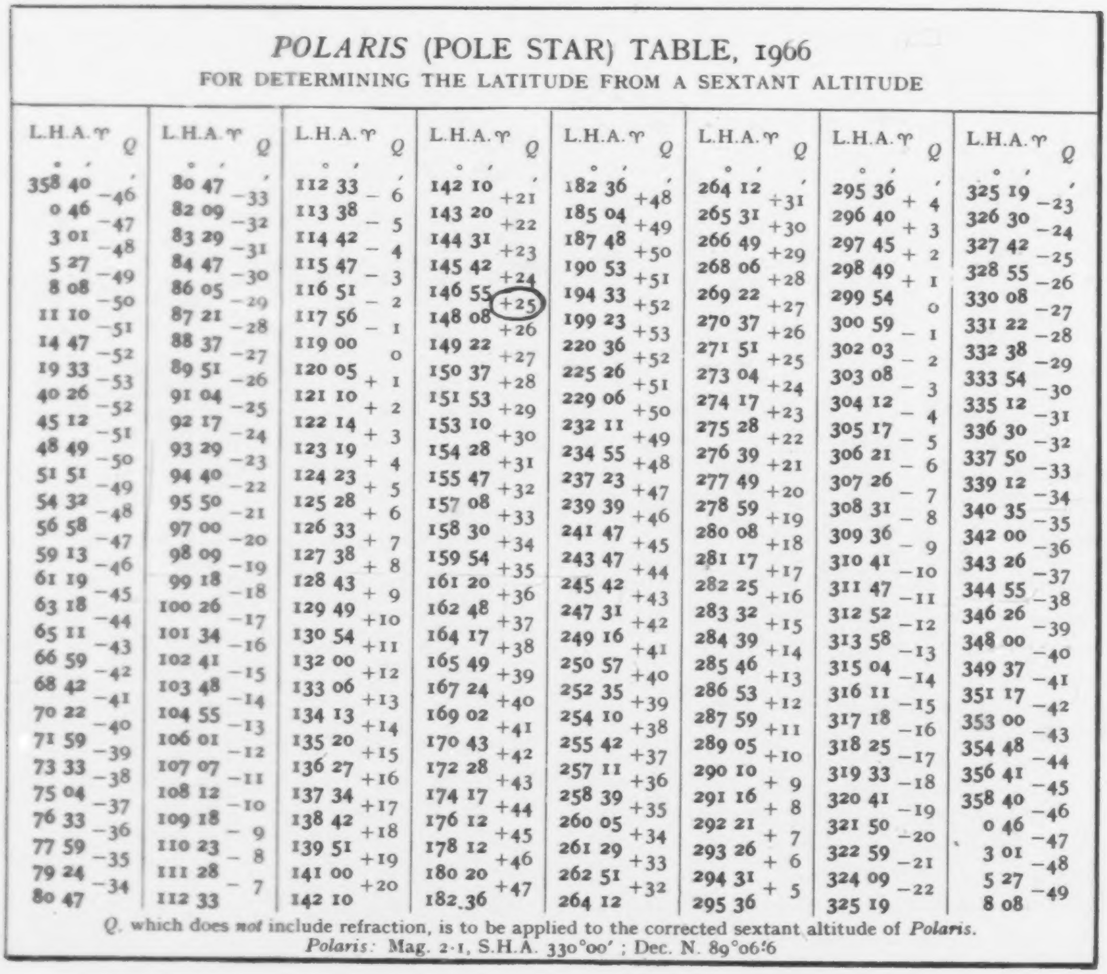
Step 3. LHA Aries of 146°59′ has a Q-factor of +25′ (figure 16-1)

Step 4.	Ho	46°59′
	Q	+ 25′
	Latitude	47°24′

Step 5. Draw LOP on chart at latitude 47°24′ (see figure 16-2)

Polaris Table in H.O. 249

The Polaris Table in Volume I of H.O. 249 (Table 6) is similar to the one in the *Air Almanac*, except that it is based on the position of Polaris for the year of the tables. If the fix is to be corrected for precession/nutation, use Table VI in H.O. 249, Volume I, rather than the Polaris table in the *Air Almanac*. The correction when applied to the fix moves the Polaris shot



POLARIS (POLE STAR) TABLE, 1966

FOR DETERMINING THE LATITUDE FROM A SEXTANT ALTITUDE

L.H.A. ♈	Q	L.H.A. ♈	Q	L.H.A. ♈	Q	L.H.A. ♈	Q	L.H.A. ♈	Q	L.H.A. ♈	Q	L.H.A. ♈	Q	L.H.A. ♈	Q
° ′	′	° ′	′	° ′	′	° ′	′	° ′	′	° ′	′	° ′	′	° ′	′
358 40	−46	80 47	−33	112 33	− 6	142 10	+21	182 36	+48	264 12	+31	295 36	+ 4	325 19	−23
0 46	−47	82 09	−32	113 38	− 5	143 20	+22	185 04	+49	265 31	+30	296 40	+ 3	326 30	−24
3 01	−48	83 29	−31	114 42	− 4	144 31	+23	187 48	+50	266 49	+29	297 45	+ 2	327 42	−25
5 27	−49	84 47	−30	115 47	− 3	145 42	+24	190 53	+51	268 06	+28	298 49	+ 1	328 55	−26
8 08	−50	86 05	−29	116 51	− 2	146 55	+25	194 33	+52	269 22	+27	299 54	0	330 08	−27
11 10	−51	87 21	−28	117 56	− 1	148 08	+26	199 23	+53	270 37	+26	300 59	− 1	331 22	−28
14 47	−52	88 37	−27	119 00	0	149 22	+27	220 36	+52	271 51	+25	302 03	− 2	332 38	−29
19 33	−53	89 51	−26	120 05	+ 1	150 37	+28	225 26	+51	273 04	+24	303 08	− 3	333 54	−30
40 26	−52	91 04	−25	121 10	+ 2	151 53	+29	229 06	+50	274 17	+23	304 12	− 4	335 12	−31
45 12	−51	92 17	−24	122 14	+ 3	153 10	+30	232 11	+49	275 28	+22	305 17	− 5	336 30	−32
48 49	−50	93 29	−23	123 19	+ 4	154 28	+31	234 55	+48	276 39	+21	306 21	− 6	337 50	−33
51 51	−49	94 40	−22	124 23	+ 5	155 47	+32	237 23	+47	277 49	+20	307 26	− 7	339 12	−34
54 32	−48	95 50	−21	125 28	+ 6	157 08	+33	239 39	+46	278 59	+19	308 31	− 8	340 35	−35
56 58	−47	97 00	−20	126 33	+ 7	158 30	+34	241 47	+45	280 08	+18	309 36	− 9	342 00	−36
59 13	−46	98 09	−19	127 38	+ 8	159 54	+35	243 47	+44	281 17	+17	310 41	−10	343 26	−37
61 19	−45	99 18	−18	128 43	+ 9	161 20	+36	245 42	+43	282 25	+16	311 47	−11	344 55	−38
63 18	−44	100 26	−17	129 49	+10	162 48	+37	247 31	+42	283 32	+15	312 52	−12	346 26	−39
65 11	−43	101 34	−16	130 54	+11	164 17	+38	249 16	+41	284 39	+14	313 58	−13	348 00	−40
66 59	−42	102 41	−15	132 00	+12	165 49	+39	250 57	+40	285 46	+13	315 04	−14	349 37	−41
68 42	−41	103 48	−14	133 06	+13	167 24	+40	252 35	+39	286 53	+12	316 11	−15	351 17	−42
70 22	−40	104 55	−13	134 13	+14	169 02	+41	254 10	+38	287 59	+11	317 18	−16	353 00	−43
71 59	−39	106 01	−12	135 20	+15	170 43	+42	255 42	+37	289 05	+10	318 25	−17	354 48	−44
73 33	−38	107 07	−11	136 27	+16	172 28	+43	257 11	+36	290 10	+ 9	319 33	−18	356 41	−45
75 04	−37	108 12	−10	137 34	+17	174 17	+44	258 39	+35	291 16	+ 8	320 41	−19	358 40	−46
76 33	−36	109 18	− 9	138 42	+18	176 12	+45	260 05	+34	292 21	+ 7	321 50	−20	0 46	−47
77 59	−35	110 23	− 8	139 51	+19	178 12	+46	261 29	+33	293 26	+ 6	322 59	−21	3 01	−48
79 24	−34	111 28	− 7	141 00	+20	180 20	+47	262 51	+32	294 31	+ 5	324 09	−22	5 27	−49
80 47		112 33		142 10		182 36		264 12		295 36		325 19		8 08	

Q, which does *not* include refraction, is to be applied to the corrected sextant altitude of *Polaris*.
Polaris: Mag. 2·1, S.H.A. 330°00′; Dec. N. 89°06′·6

Figure 16-1. Extracting "Q" Correction

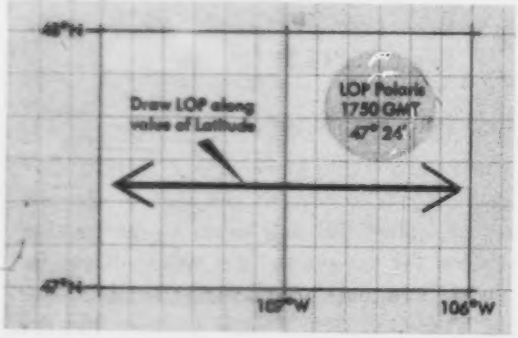


Figure 16-2. Polaris Solution, Step 5

into its correct position. When the *Air Almanac* is used, Polaris is plotted in its correct position, and applying precession/nutation correction would move Polaris to an incorrect position.

The *intercept method* of plotting a Polaris LOP makes it possible to apply Coriolis correction to the assumed position and save time getting the fix onto the chart. To plot a Polaris LOP as an intercept instead of as a parallel of latitude, adjust the assumed position for Coriolis, and apply the Q-factor with the reverse sign to the assumed latitude to obtain the Hc of Polaris. Comparison of this Hc with Ho determines the intercept to be plotted towards or away from the true azimuth of Polaris.

Example:

Assumed latitude	40°00′ N
Q (reversed sign)	−17′
Hc Polaris	39°43′
Ho Polaris	39°54′
Intercept	11 NM toward 360°

The true azimuth of Polaris for the time of the shot may be used instead of 360°. This results in a slight increase in accuracy.

LHA METHOD OF OBTAINING FIX

The first step in obtaining a celestial fix by the LHA method is to solve a precomputation for the time of the fix, as shown in figure 16-3. In solving for the time of 0600, an LHA of 157° is determined. An LHA for 0556, or four minutes prior to fix time, and 0552, or eight minutes prior to fix time, are selected; i.e., 156° and 155°, respectively. Enter Volume I of H.O. 249 and find the Hc and Zn for the respective LHAs.

When shooting the selected bodies, take care to shoot them exactly on the prescribed times. No motion corrections are necessary in obtaining a fix by this method because the assumed positions are moved for track and groundspeed, as shown in figure 16-4.

If your shots are not made exactly on the prescribed times, move the assumed position 15′ of longitude to the east for every minute early and 15′ of longitude to the west for every minute late.

DAYTIME CELESTIAL TECHNIQUES

Daytime fixing, using celestial techniques, is rather limited because often only one body, the sun, is visible. Ordinarily, three LOPs cannot be obtained for a fix from one body because the LOPs fall too nearly parallel to each other. There is a technique, however, which can be used to determine a fix from observations of one body.

The Noonday Fix

At low latitudes when the sun passes close to the observer's position, usually within 10°, its azimuth changes rapidly before and after transit. Over a short period of time the azimuth may change enough to allow a fix to be obtained.

10 APRIL 1972			
	FIX TIME	0600	
BODY	Pollux	SPICA	KOCHAB
DR LAT	3821 N		
DR LONG	13129 W		
GHA			28834
CORR			—
SHA			—
GHA			28834
PLUS 360°			—
ASSUM - W LONG + F			131 34
LHA	155	156	157
ASSUM LAT			38N
DEC			—
TRACK			045
ZN			—
ZN - TR			—
GS			400
ACFT ALT			29.0
MOT OBS			—
MOT BODY			—
COMB ADJ			—
HS TIME	0552	0556	0600
HS	5643	2512	4313
CORR SEXT	0	0	0
CORR REFR	0	-1	0
CORR PA SD			—
CORR TOTAL	0	-1	0
HO	5643	2511	4313
TOT ADJ	—	—	—
ADJ HO	5643	2511	4313
TAB HC			
CORR D			
CORR DEC			
CORR HC	5601	2529	4253
INTCP TA	42T	18A	20T
ZN	265	130	020
CONV ANG	①	②	③
GRID AZ			
CORIOLIS			7R
P - N			2/110°
POL CORR			
POL LAT			

Figure 16-3. Precomputation for the Time of the Fix

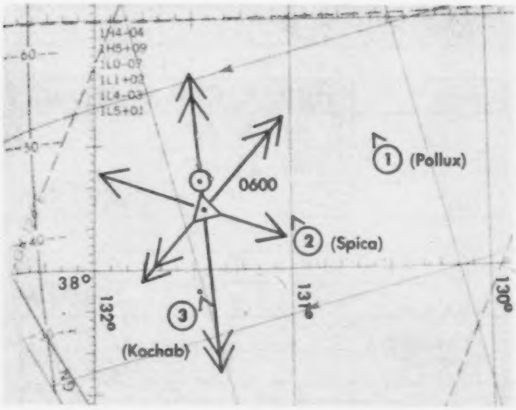


Figure 16-4. Assumed Positions Moved for Track and Groundspeed

Since two of the LOPs must be moved by using dead reckoning information, the noonday fix may be less accurate than other celestial fixes. It is better, however, than the single LOP positions which are obtained during the other portions of the day.

The intercept method is normally used in obtaining a noonday fix. If the sun passes close to the observer's position, within about 4°, the subpoint method of plotting the fix may be used.

INTERCEPT METHOD. This method differs from normal procedures in that three LHAs of the sun are computed, and three assumed positions are plotted. Because of the rapid change of the sun's azimuth at or near transit, this variation is necessary. The procedure is:

Step 1. Determine the time of transit. This will be when the LHA is 360°.

Step 2. By inspection, select the LHA before and after transit for which the change in azimuth is 30° or more. Since 1° of LHA is equal to four minutes of time, the difference in transit LHA and the new LHA can be converted to time in minutes. Thus, the time preceding and following transit can be determined.

Step 3. Plot the DR positions for times determined in step 2. Select the appropriate assumed positions necessary for the computation and plotting of the LOPs. The assumed position for time of transit is also plotted.

Step 4. After observations are made, determine the intercepts and azimuth for each LOP. Plot these data from the respective assumed positions.

Step 5. Resolve the LOPs to a common time, preferably that of the transit LOP.

NOTE: On a westerly to easterly heading, the azimuths between observations will change somewhat more than the 30° obtained from visual inspection. On an easterly to westerly heading, this change will be somewhat less. At 30° North latitude, the linear speed of the sun is approximately 780 knots. Thus, on westerly headings in high-speed aircraft, the DR distance involved before encountering a 30° change in azimuth will be considerable.

SUBPOINT METHOD. When the observer is within approximately 4° of the subpoint of the body, the subpoint method of solution is normally used, because the radius of the circle of equal altitude is so small that a straight line does not approximate the arc, and a straight line will not give an accurate LOP.

The procedure is:

Step 1. Plot the subpoints of the body for the time of the observations.

Step 2. Find the co-altitude of the shots and convert it to nautical miles.

Step 3. Advance the first subpoint and retard the third along the DR track, using the best known track and groundspeed.

Step 4. Using a compass or a pair of dividers, set the distance found from the co-altitude and strike it off from the resolved subpoints. Do this for each observation.

Step 5. The resulting intersection or triangle will give a noonday fix. If the LOPs form a triangle, the aircraft position is probably within the triangle.

Combinations of Sun, Moon, and Venus

Fairly often either the moon or Venus or both of these bodies are visible during daylight hours and can be used to obtain an LOP. The possibility of fixes, using combinations of these bodies and the sun, should always be considered when planning daylight celestial flights. When planning the flight, the navigator should use the Sky Diagrams in the *Air Almanac* to determine the availability of the moon and Venus. If the bodies are available, they can be found readily by precomputing their altitude and azimuth.

When using the moon, as at night, it is wise to shoot the upper or lower limb and use semidiameter correction rather than try to estimate its center, except when the moon is full.

During the day when the sun is high, the moon or Venus, if they are available, can be used to obtain compass deviation checks. In polar regions during periods of continuous twilight, the moon and Venus will be available if their declination is the same name as the latitude.

THE LANDFALL

Before the development of accurate methods of celestial navigation, a mariner had no way of checking his dead reckoning when he was out of sight of land. In crossing an ocean, he might accumulate a large DR error. If his destination were on a continent or large island, he could follow the coastline to destination. But if the coastline which he first sighted were poorly charted he might be unable to find his position. Then he would not know which way to turn to reach destination. The mariner sometimes solved this problem by deliberately setting a course to one side of his destination; then upon reaching the coast, he knew which way to turn. This procedure is known as *making a landfall*. In figure 16-5, the mariner purposely sails left of destination; then when striking the coast, he knows that he must turn right.

Like the mariner, the air navigator may reach his destination by using some LOP which passes through it. This LOP may be a coastline, a river, a railroad, a lightline, or a radio beam. Usually he will simply follow the LOP; however, like the mariner, he may set a course definitely to one side so that he will know which way to turn when he strikes the LOP. When the navigator uses a visible LOP in this manner, he is flying a terrestrial landfall.

To an air navigator, "landfall" means "celestial landfall." A celestial landfall is similar to the terrestrial landfall except that it uses a celestial LOP, which is invisible.

The celestial landfall is the most certain method of reaching destination when the navigator is unable to supplement his dead reckoning except with LOPs from one celestial body.

If the navigator is aiming for a small island, course is more important than groundspeed. If his track is correct, he will pass over the island sooner or later, no matter how inaccurate his ETA. But if he is off course and misses the island completely, an accurate groundspeed is poor consolation. If the LOPs were all perfect course lines, it would be comparatively easy to reach destination.

The cut of the LOPs depends on the direction of the track relative to the azimuth of the sun. If the navigator can set his departure time, he may be able to reach the vicinity of destination when the LOPs give a favorable cut, but possibly

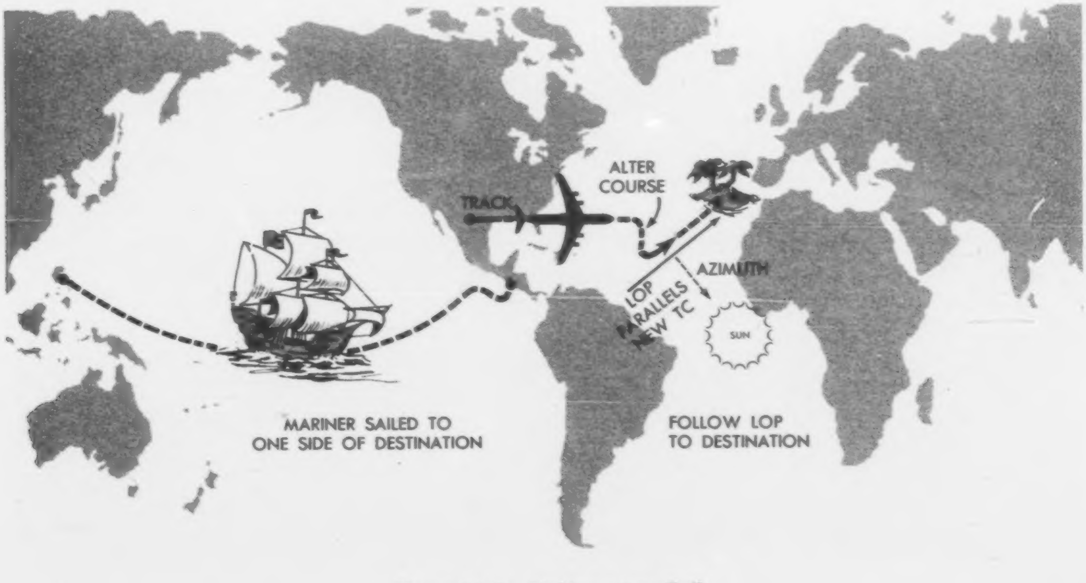

TRACK
ALTER COURSE
AZIMUTH
LOP PARALLELS NEW TC
SUN
MARINER SAILED TO ONE SIDE OF DESTINATION
FOLLOW LOP TO DESTINATION

Figure 16-5. Making a Landfall

that will be the time of day when the azimuth is changing most rapidly.

Another solution is to alter course near destination and approach destination from such a direction that the LOPs are course lines. This is a landfall. In figure 16-5, the LOPs were neither speed lines nor course lines, so the aircraft altered course in such a manner that the new course to destination was parallel to the LOPs.

In a landfall, course is of the utmost importance, and ETA is secondary. The object of a landfall is to correct course by means of celestial LOPs so that the navigator will pass over destination. Essentially, he flies along an LOP or celestial true course line, which passes through destination. Thus, the celestial landfall is the method of using celestial LOPs as course lines into destination, no matter how they cut the true course from departure to destination.

The celestial landfall presents two problems. The first problem is to get onto a celestial true course to destination. In order to do so, the navigator must know the position of the true course line, he must know when he reaches it, and he must know when he is flying on it. The second problem is to fly in the right direction on the true course line. It would be a fatal mistake in mid-Pacific to turn the wrong way and follow the true course line away from destination.

Although all landfalls work on the same principle, there are variations in procedure depending on whether the LOPs are more nearly course lines, or more nearly speed lines on the true course. Accordingly, landfalls are classified as speed-line landfalls and course-line landfalls.

Course-Line Landfall

Step 1. Refer to figure 16-6. Shoot and plot an LOP (A). Advance LOP (A) 10 minutes along track to establish LOP (A_1). This allows for working time. Plot LOP (A_2) through destination parallel to LOP (A). LOP (A_2) represents the celestial true course to destination.

Step 2. Determine the perpendicular true course to LOP (A_2) from LOP (A_1).

Step 3. Compute the ETA to the celestial true course (A_2). At the expiration of this ETA, alter onto the celestial true course to destination.

Step 4. Additional celestial observations should be taken to update the previous calculations.

NOTE: Celestial landfall procedures should be started at least one hour before the ETA to destination.

Speed-Line Landfall

Step 1. Refer to figure 16-7. Shoot and plot a line of position (A). Advance LOP (A) 10 minutes along track to establish LOP (A_1). This allows for working time. Plot LOP (A_2) through destination parallel to LOP (A).

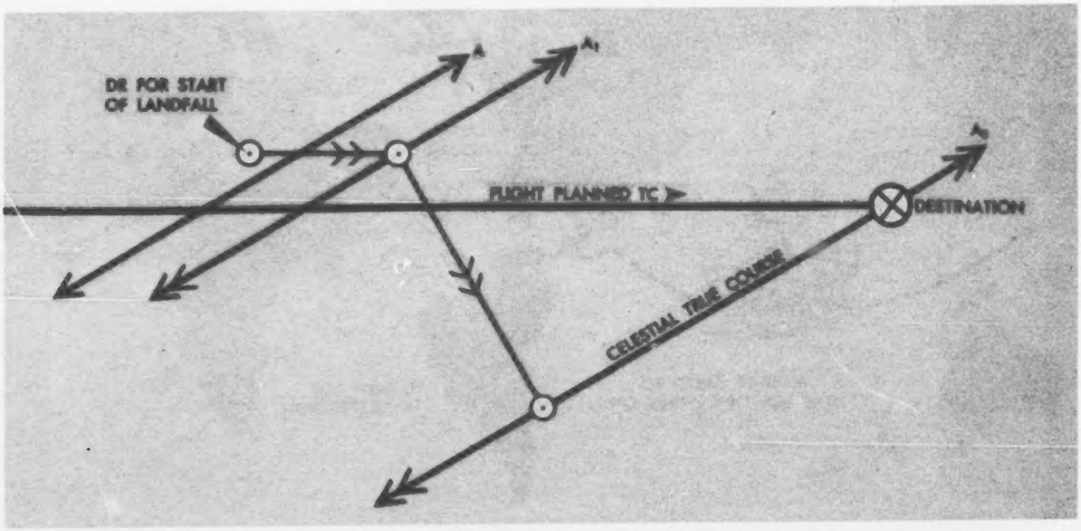


Figure 16-6. Course-Line Celestial Landfall

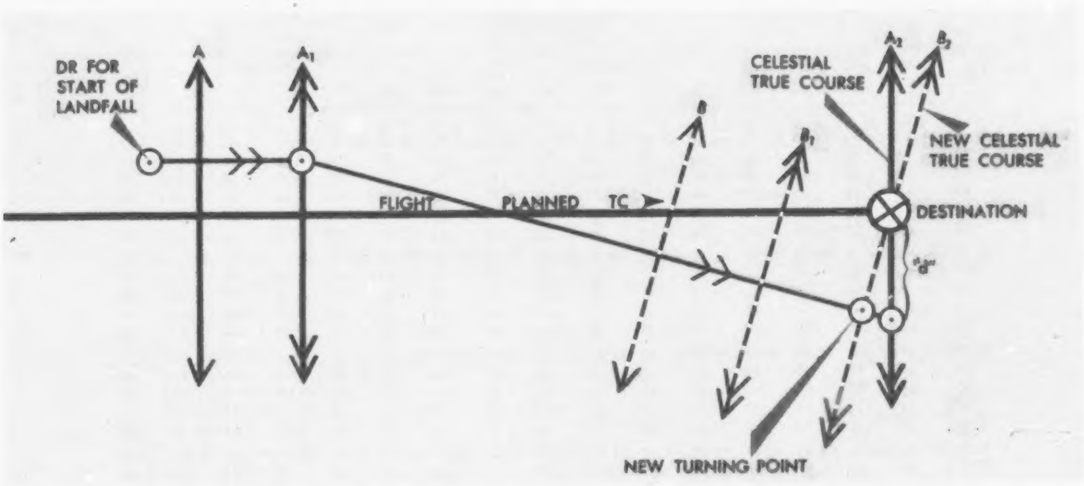


Figure 16-7. Speed-Line Celestial Landfall

Step 2. Plot a distance *"d"* from destination along LOP (A_2) representing 10% of the distance flown from the previous fix but not less than 60 NM.

Step 3. Alter heading at LOP (A_1) to the position on LOP (A_2) determined by *"d"*. Before the course to this position is determined, the direction which LOP (A_2) is changing must be considered to determine whether to alter right or left of the flight planned true course.

Step 4. Repeat this procedure at least 30 minutes prior to the ETA to LOP (A_2) to establish LOPs (B), (B_1), and to compute a new celestial true course (B_2).

Step 5. Alter to destination upon intersecting LOP (B_2).

DURATION OF LIGHT

At high latitudes it is possible to remain in twilight throughout an entire flight. Therefore, it is important to plan such a flight so as to have some celestial bodies available for navigation.

Sunrise, Sunset, and Twilight at Sea Level

The times of sunrise and sunset for latitudes 60° South to 72° North are printed in the *Air Almanac,* as shown in figure 16-8. These tables give the local mean time (LMT) of sunrise and sunset at suitable intervals of latitude.

To obtain the GMT of sunrise or sunset at a particular location, convert the longitude to time and apply it to the LMT of sunrise or sunset using the following formula:

GMT = LMT − East (+ West) longitude.

The tables used to compute *beginning of morning twilight (BMT) and end of evening twilight (EET)* are used in the same manner as the sunrise and sunset tables (see figure 16-9). The duration of twilight is obtained by subtracting BMT from sunrise or subtracting sunset from EET.

Example:

Find the GMT of BMT and sunrise, and find the duration of twilight at 33°20′N, 135°39′E on 1 September 1965. Enter the tables in figures 16-8 and 16-9 with latitude and the *nearest* date. The following information is extracted from the 2 September columns:

BMT	*SUNRISE*
05^h09^m LMT 1 Sep	05^h34^m LMT 1 Sep
-09^h03^m E Long	-09^h03^m E Long
2006 GMT 31 Aug	2031 GMT 31 Aug

2031 GMT sunrise minus 2006 GMT of BMT equals the duration of twilight (25 min).

Sunrise, Sunset, and Twilight at Altitude

A navigator at altitude sees the sun earlier in the morning and later in the evening than one does at sea level; therefore, a correction to sunrise and sunset for the altitude of the observer is

SUNRISE

Lat.	Aug.	September										October				Lat.
	30	2	5	8	11	14	17	20	23	26	29	2	5	8	11	
°	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	°
N 72	03 49	04 04	04 18	04 33	04 47	05 00	05 14	05 27	05 41	05 54	06 08	06 21	06 35	06 49	07 03	N 72
70	04 04	17	30	42	04 54	06	18	30	42	54	06	18	30	42	06 54	70
68	17	28	39	50	05 01	11	22	32	43	54	04	15	26	36	47	68
66	27	37	47	04 56	06	15	25	34	44	53	03	12	22	32	41	66
64	35	44	53	05 02	10	19	27	36	44	53	02	10	19	28	36	64
62	43	51	04 59	06	14	22	30	37	45	53	06 01	08	16	24	32	62
N 60	04 49	04 56	05 03	05 10	05 17	05 24	05 31	05 38	05 45	05 52	05 59	06 07	06 14	06 21	06 28	N 60
58	54	05 01	07	14	20	27	33	39	46	52	59	05	12	18	25	58
56	04 59	05	11	17	23	28	34	40	46	52	58	04	10	16	22	56
54	05 04	09	14	20	25	30	36	41	46	52	57	03	08	14	19	54
52	07	12	17	22	27	32	37	42	47	52	57	02	07	12	17	52
N 50	05 11	05 16	05 20	05 24	05 29	05 33	05 38	05 42	05 47	05 51	05 56	06 01	06 05	06 10	06 15	N 50
45	19	22	26	29	33	37	40	44	48	51	55	05 58	02	06	10	45
40	25	28	31	34	37	39	42	45	48	51	54	57	06 00	06 03	06	40
35	31	33	35	37	39	42	44	46	48	50	53	55	05 57	05 59	06 02	35
30	35	37	39	40	42	44	45	47	48	50	52	54	55	57	05 59	30
N 20	05 44	05 44	05 45	05 46	05 46	05 47	05 48	05 48	05 49	05 50	05 50	05 51	05 52	05 52	05 53	N 20
N 10	51	51	51	50	50	50	50	49	49	49	49	49	48	48	48	N 10
0	05 57	05 56	05 55	54	53	52	51	50	49	48	47	46	45	44	44	0
S 10	06 04	06 02	06 00	05 59	05 57	55	53	51	49	47	46	44	42	40	39	S 10
20	11	08	05	06 03	06 00	05 57	55	52	49	47	44	41	38	36	33	20
S 30	06 18	06 15	06 11	06 08	06 04	06 00	05 57	05 53	05 49	05 45	05 42	05 38	05 34	05 31	05 27	S 30
35	23	19	14	10	06	02	57	53	49	44	40	36	32	28	24	35
40	27	23	18	13	08	03	05 59	54	49	44	39	34	29	24	19	40
45	33	28	22	17	11	05	06 00	54	48	43	37	31	26	20	15	45
50	40	33	27	21	14	08	01	54	48	41	35	28	22	15	09	50
S 52	06 43	06 36	06 29	06 22	06 16	06 09	06 02	05 55	05 48	05 41	05 34	05 27	05 20	05 13	05 06	S 52
54	46	39	32	25	17	10	02	55	47	40	33	25	18	10	03	54
56	50	42	35	27	19	11	03	55	47	39	31	23	15	08	05 00	56
58	54	46	38	29	21	12	04	55	47	38	30	21	13	05	04 56	58
S 60	06 59	06 50	06 41	06 32	06 23	06 14	06 05	05 56	05 47	05 37	05 28	05 19	05 10	05 01	04 52	S 60

SUNSET

Lat.	Aug.	September										October				Lat.
	30	2	5	8	11	14	17	20	23	26	29	2	5	8	11	
°	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	°
N 72	20 10	19 53	19 36	19 20	19 04	18 49	18 33	18 18	18 02	17 47	17 31	17 16	17 01	16 45	16 30	N 72
70	19 54	40	26	11	18 57	43	29	15	01	47	34	20	06	52	38	70
68	42	30	17	19 04	51	38	26	13	01	48	35	23	10	16 58	45	68
66	33	21	09	18 58	46	35	23	11	18 00	48	37	26	14	17 03	51	66
64	25	14	19 03	53	42	31	21	10	17 59	49	38	28	17	07	16 56	64
62	17	08	18 58	48	38	29	19	09	59	49	39	30	20	10	17 01	62
N 60	19 11	19 02	18 53	18 44	18 35	18 26	18 17	18 08	17 58	17 49	17 40	17 31	17 22	17 13	17 04	N 60
58	06	18 57	49	41	32	24	15	07	58	50	41	33	25	16	08	58
56	19 01	53	45	38	30	22	14	06	58	50	42	34	26	18	11	56
54	18 57	49	42	35	27	20	12	05	58	50	43	35	28	21	14	54
52	53	46	39	32	25	18	11	04	57	50	43	36	29	23	16	52
N 50	18 49	18 43	18 37	18 30	18 24	18 17	18 10	18 04	17 57	17 51	17 44	17 38	17 31	17 25	17 18	N 50
45	42	36	31	25	20	14	08	03	57	51	46	40	34	29	23	45
40	36	31	26	21	16	11	06	01	56	51	47	42	37	32	27	40
35	30	26	22	18	13	09	05	01	56	52	48	43	39	35	31	35
30	25	22	18	15	11	07	04	18 00	56	52	49	45	41	38	34	30
N 20	18 17	18 15	18 12	18 10	18 07	18 04	18 01	17 59	17 56	17 53	17 50	17 48	17 45	17 43	17 40	N 20
N 10	10	09	07	05	03	18 01	18 00	58	56	54	52	50	49	47	45	N 10
0	18 04	18 03	18 02	18 01	18 00	17 59	17 58	57	56	55	54	53	52	51	50	0
S 10	17 58	17 58	17 57	17 57	17 57	57	56	56	56	56	55	55	55	17 55	17 55	S 10
20	51	52	52	53	54	54	55	55	56	57	17 57	17 58	17 59	18 00	18 01	20
S 30	17 44	17 45	17 47	17 48	17 50	17 52	17 53	17 55	17 56	17 58	18 00	18 02	18 03	18 05	18 07	S 30
35	39	42	44	46	48	50	52	55	57	17 59	01	04	06	09	11	35
40	35	37	40	43	46	49	51	54	57	18 00	03	06	09	12	15	40
45	29	33	36	40	43	47	50	54	58	01	05	09	12	16	20	45
50	23	27	31	36	40	45	49	54	58	03	07	12	17	21	26	50
S 52	17 20	17 24	17 29	17 34	17 39	17 44	17 49	17 53	17 58	18 03	18 08	18 13	18 18	18 24	18 29	S 52
54	16	21	27	32	37	43	48	53	59	04	10	15	21	26	32	54
56	13	18	24	30	36	41	47	53	59	05	11	17	23	29	35	56
58	09	15	21	27	34	40	46	53	17 59	06	12	19	25	32	39	58
S 60	17 04	17 11	17 18	17 25	17 32	17 39	17 46	17 53	18 00	18 07	18 14	18 21	18 28	18 36	18 43	S 60

Figure 16-8. Sunrise and Sunset Tables

MORNING CIVIL TWILIGHT

Lat.	Aug.	September										October				Lat.
	30	2	5	8	11	14	17	20	23	26	29	2	5	8	11	
°	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	°
N 72	02 12	02 35	02 55	03 14	03 31	03 47	04 03	04 18	04 32	04 46	05 00	05 14	05 27	05 41	05 54	N 72
70	02 45	03 02	03 18	33	03 48	04 01	15	28	40	53	05	17	29	41	52	70
68	03 08	22	36	03 48	04 01	13	24	36	47	04 58	09	19	30	41	51	68
66	27	38	03 50	04 01	11	22	32	42	52	05 02	12	21	31	40	50	66
64	41	03 51	04 01	11	20	30	39	48	04 57	06	14	23	32	40	49	64
62	03 53	04 02	11	19	28	36	44	52	05 01	09	16	24	32	40	48	62
N 60	04 03	04 13	04 19	04 27	04 34	04 42	04 49	04 57	05 04	05 11	05 18	05 25	05 33	05 40	05 47	N 60
58	12	19	26	33	40	47	53	05 00	07	13	20	26	33	39	40	58
56	19	26	32	38	45	51	04 57	03	09	15	21	27	33	39	45	56
54	26	32	37	43	49	54	05 00	06	11	17	22	27	33	38	44	54
52	32	37	42	47	53	04 58	03	08	13	18	23	28	33	38	43	52
N 50	04 37	04 42	04 47	04 51	04 56	05 01	05 05	05 10	05 15	05 19	05 24	05 29	05 33	05 38	05 42	N 50
45	48	04 52	04 56	05 00	05 03	07	11	15	18	22	26	29	33	37	40	45
40	04 57	05 00	05 03	06	09	12	15	18	21	24	27	30	33	35	38	40
35	05 05	07	09	12	14	16	18	21	23	25	27	30	32	34	37	35
30	11	13	15	16	18	20	21	23	25	26	28	30	31	33	35	30
N 20	05 21	05 22	05 23	05 24	05 24	05 25	05 26	05 26	05 27	05 28	05 28	05 29	05 30	05 30	05 31	N 20
N 10	30	29	29	29	29	29	29	28	28	28	28	28	27	27	27	N 10
0	36	35	35	34	33	32	31	30	29	28	27	25	25	24	23	0
S 10	43	41	39	38	36	34	32	30	28	26	25	23	21	19	18	S 10
20	48	46	43	41	38	35	33	30	27	24	22	19	16	14	11	20
S 30	05 54	05 51	05 47	05 44	05 40	05 36	05 33	05 29	05 25	05 21	05 18	05 14	05 10	05 07	05 03	S 30
35	05 57	53	49	45	41	37	32	28	24	19	15	11	06	05 02	04 58	35
40	06 00	55	51	46	41	36	32	27	22	17	12	07	05 02	04 57	52	40
45	03	05 58	53	47	42	36	31	25	19	13	07	05 02	04 56	50	44	45
50	07	06 01	55	48	42	35	29	22	16	09	02	04 56	49	42	36	50
S 52	06 09	06 02	05 56	05 49	05 42	05 35	05 28	05 21	05 14	05 07	05 00	04 53	04 45	04 38	04 31	S 52
54	10	03	56	49	42	35	27	20	12	05	04 57	49	42	34	26	54
56	12	05	57	50	42	34	26	18	10	05 02	54	46	38	29	21	56
58	14	06	58	50	42	33	25	16	08	04 59	50	42	33	24	15	58
S 60	06 16	06 08	05 59	05 50	05 42	05 33	05 24	05 14	05 05	04 56	04 46	04 37	04 27	04 18	04 08	S 60

EVENING CIVIL TWILIGHT

Lat.	Aug.	September										October				Lat.
	30	2	5	8	11	14	17	20	23	26	29	2	5	8	11	
°	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	°
N 72	21 44	21 20	20 58	20 38	20 19	20 01	19 44	19 27	19 10	18 54	18 38	18 23	18 08	17 53	17 38	N 72
70	21 12	20 54	36	19	20 03	19 47	32	17	19 03	48	34	20	07	53	40	70
68	20 50	34	19	20 04	19 50	36	23	09	18 56	43	31	18	06	53	41	68
66	32	19	20 06	19 53	40	27	15	19 03	51	39	28	16	05	54	43	66
64	18	20 06	19 55	43	32	20	09	18 58	47	36	25	15	04	54	44	64
62	20 07	19 56	45	35	24	14	19 04	53	43	33	23	14	04	54	45	62
N 60	19 57	19 47	19 37	19 28	19 18	19 08	18 59	18 50	18 40	18 31	18 22	18 13	18 04	17 55	17 46	N 60
58	48	39	30	22	13	19 04	55	46	38	29	20	12	03	55	47	58
56	41	32	24	16	08	18 59	51	43	35	27	19	11	03	56	48	56
54	34	26	19	11	03	56	48	40	33	25	18	10	03	56	49	54
52	28	21	14	07	19 00	52	45	38	31	24	17	10	03	56	50	52
N 50	19 23	19 16	19 10	19 03	18 56	18 50	18 43	18 36	18 29	18 23	18 16	18 10	18 03	17 57	17 51	N 50
45	12	19 07	19 01	18 55	49	43	38	32	26	20	15	09	03	58	53	45
40	19 03	18 59	18 54	49	44	39	34	28	23	18	13	09	04	17 59	55	40
35	18 56	52	48	43	39	35	30	26	21	17	13	09	04	18 00	56	35
30	50	46	43	39	35	31	27	24	20	16	12	09	05	02	17 58	30
N 20	18 40	18 37	18 34	18 32	18 29	18 26	18 23	18 21	18 18	18 15	18 12	18 10	18 07	18 05	18 02	N 20
N 10	32	30	28	26	24	22	21	19	17	15	13	11	10	08	06	N 10
0	25	24	23	22	21	20	19	18	16	15	14	13	13	12	11	0
S 10	19	19	18	18	18	18	17	17	17	17	17	16	16	16	16	S 10
20	13	14	14	15	16	16	17	18	18	19	20	20	21	22	23	20
S 30	18 08	18 09	18 11	18 12	18 14	18 16	18 17	18 19	18 20	18 22	18 24	18 26	18 27	18 29	18 31	S 30
35	05	07	09	11	13	16	18	20	22	24	27	29	32	34	37	35
40	18 02	05	07	10	13	16	18	21	24	27	30	33	36	39	43	40
45	17 59	18 02	06	09	13	16	20	23	27	31	34	38	42	46	50	45
50	55	17 59	04	08	12	17	21	26	31	35	40	45	49	54	18 59	50
S 52	17 54	17 58	18 03	18 08	18 12	18 17	18 22	18 27	18 32	18 37	18 42	18 47	18 53	18 58	19 04	S 52
54	52	57	02	07	13	18	23	29	34	40	45	51	18 57	19 03	09	54
56	50	56	01	07	13	18	24	30	36	42	48	55	19 01	08	14	56
58	48	54	01	07	13	19	26	32	39	45	52	18 59	06	13	20	58
S 60	17 46	17 53	18 00	18 06	18 13	18 20	18 27	18 34	18 41	18 49	18 56	19 04	19 12	19 19	19 28	S 60

Figure 16-9. BMT and EET Tables

necessary. This correction is also applicable to BMT and EET. The tables and graphs which enable the navigator to determine these corrections are in the *Air Almanac*. Table 1, figure 16-10, supplies the LMT of meridian passage and declination of the sun. Table 2 provides the depression angle of the sun for various heights of the observer. The depression angle is the angular distance below the natural horizon between the center of a celestial body and the horizon at sea level. Table 3 gives the depression angle for twilight. The Rising, Setting and Depression graphs, shown in figure 16-11, are entered at the appropriate latitude with the depression angle and declination obtained from Tables 1 and 2. The hour angle value, obtained from the graph, is applied to the meridian passage (local apparent noon) supplied in Table 1, figure 16-10. The result is the LMT of the phenomenon being computed.

RISING, SETTING AND DEPRESSION GRAPHS

TABLE 1—MERIDIAN PASSAGE AND DECLINATION OF THE SUN AT 12ʰ G.M.T.

Day	September		October		November		December	
	Mer. Pass.	Dec.	Mer. Pass.	Dec.	Mer. Pass.	Dec.	Mer. Pass.	Dec.
	h m	°	h m	°	h m	°	h m	°
1	12 00	N. 8·3	11 50	S. 3·2	11 44	S.14·5	11 49	S.21·8
2	12 00	7·9	49	3·6	44	14·8	49	22·0
3	11 59	7·5	49	4·0	44	15·1	50	22·1
4	59	7·2	49	4·4	44	15·4	50	22·3
5	59	6·8	48	4·8	44	15·7	51	22·4
6	11 58	N. 6·4	11 48	S. 5·1	11 44	S.16·0	11 51	S.22·5
7	58	6·0	48	5·5	44	16·3	51	22·6
8	58	5·7	48	5·9	44	16·6	52	22·7
9	57	5·3	47	6·3	44	16·9	52	22·8
10	57	4·9	47	6·7	44	17·2	53	22·9
11	11 57	N. 4·5	11 47	S. 7·0	11 44	S.17·4	11 53	S.23·0
12	56	4·2	47	7·4	44	17·7	54	23·1
13	56	3·8	46	7·8	44	18·0	54	23·2
14	56	3·4	46	8·2	44	18·2	55	23·2
15	55	3·0	46	8·5	45	18·5	55	23·3
16	11 55	N. 2·6	11 46	S. 8·9	11 45	S.18·8	11 56	S.23·3
17	55	2·2	45	9·3	45	19·0	56	23·4
18	54	1·8	45	9·6	45	19·2	57	23·4
19	54	1·5	45	10·0	45	19·5	57	23·4
20	53	1·1	45	10·4	46	19·7	58	23·4
21	11 53	N. 0·7	11 45	S.10·7	11 46	S.19·9	11 58	S.23·4
22	53	N. 0·3	45	11·1	46	20·2	59	23·4
23	52	S. 0·1	44	11·4	46	20·4	11 59	23·4
24	52	0·5	44	11·8	47	20·6	12 00	23·4
25	52	0·9	44	12·1	47	20·8	00	23·4
26	11 51	S. 1·3	11 44	S.12·5	11 47	S.21·0	12 01	S.23·4
27	51	1·7	44	12·8	48	21·1	01	23·3
28	51	2·0	44	13·1	48	21·3	02	23·3
29	50	2·4	44	13·5	48	21·5	02	23·2
30	11 50	S. 2·8	44	13·8	11 49	S.21·7	03	23·2
31			11 44	S.14·1			12 03	S.23·1

TABLES 2 and 3—DEPRESSION OF THE SUN AT VARIOUS HEIGHTS

Height	TABLE 2 AT SUNRISE AND SUNSET		TABLE 3 AT CIVIL TWILIGHT	
Feet	Depression	Diff. from 0°·8	Depression	Diff. from 0°·8
	°	°	°	°
0	0·8	—	6·0	5·2
500	1·3	0·5	6·0	5·2
1 000	1·5	0·7	6·0	5·2
2 000	1·7	0·9	6·1	5·3
3 000	1·9	1·1	6·1	5·3
4 000	2·1	1·3	6·1	5·3
5 000	2·2	1·4	6·2	5·4
6 000	2·4	1·6	6·2	5·4
7 000	2·5	1·7	6·2	5·4
8 000	2·6	1·8	6·3	5·5
9 000	2·7	1·9	6·3	5·5
10 000	2·8	2·0	6·3	5·5
15 000	3·2	2·4	6·5	5·7
20 000	3·6	2·8	6·6	5·8
25 000	3·9	3·1	6·8	6·0
30 000	4·2	3·4	6·9	6·1
35 000	4·4	3·6	7·1	6·3
40 000	4·7	3·9	7·2	6·4
45 000	4·9	4·1	7·3	6·5
50 000	5·1	4·3	7·5	6·7
55 000	5·3	4·5	7·6	6·8
60 000	5·5	4·7	7·7	6·9

Figure 16-10. Tables for Rising, Setting, and Depression Graphs

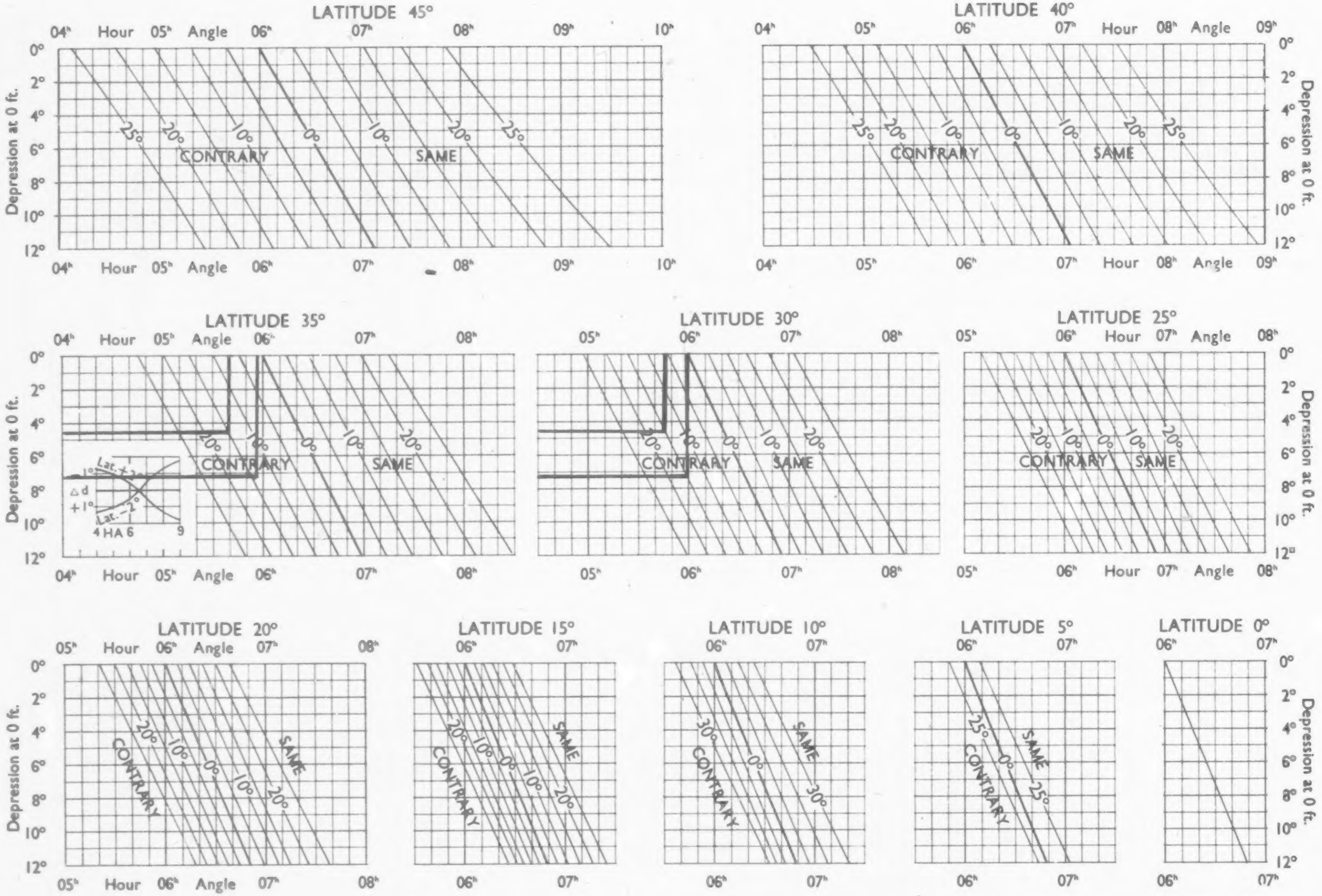


Figure 16-11. Rising, Setting, and Depression Graphs

THESE GRAPHS GIVE THE HOUR ANGLE (E. OR W.) CORRESPONDING TO DEPRESSIONS BELOW THE HORIZON OF 0° TO 12°.

Example:

Find the times of BMT, Sunrise, Sunset, and EET on 1 November 1965 for latitude 33°20′N at altitude 40,000 feet.

Step 1. In Table 1, figure 16-10, the meridian passage of the sun is 11^h44^m and the declination is S 14½°.

Step 2. The depression angles are extracted from Tables 2 and 3:

Sunrise/Sunset	4.7°
Twilight	7.2°

Step 3. The Rising, Setting, and Depression Graphs, shown in figure 16-11, give the hour angles (time factors) to be applied to meridian passage. Enter graphs with depression angle, go horizontally to declination of body, then vertically to extract hour angle.

In this example, the hour angle must be interpolated between latitudes 35° and 30° since data is being computed for 33°-20′N.

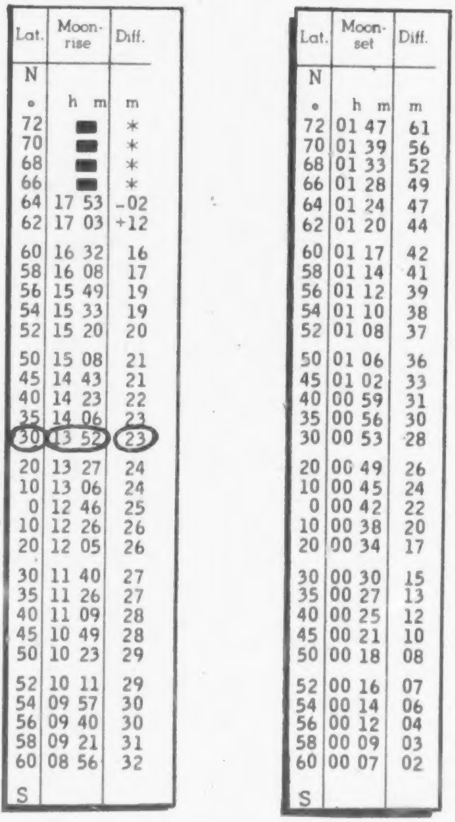
	Depress Angle	*Meridian Passage*	*Hour Angle 35°N*	*Hour Angle 30°N*	*Hour Angle 33°-20N*	*LMT*
BMT	7.2°	11^h44^m	5^h55^m	5^h59^m	-5^h57^m	$=0547$
Sunrise	4.7°	11^h44^m	5^h40^m	5^h46^m	-5^h43^m	$=0601$
Sunset	4.7°	11^h44^m	5^h40^m	5^h46^m	$+5^h43^m$	$=1727$
EET	7.2°	11^h44^m	5^h55^m	5^h59^m	$+5^h57^m$	$=1741$

Rule for applying hour angle:
Subtract for rising; add for setting.

Moonrise and Moonset

On each daily page of the *Air Almanac* is a tabulation of moonrise and moonset given for specific intervals of latitude. See figure 16-12. The rate at which the moon transits each meridian is different than that of the sun. Therefore, the times listed are GMT of moonrise or moonset at the Greenwich meridian only. To obtain the GMT of the phenomena at the observer's meridian, the tabulated times must first be converted to LMT of the observer.

Enter the table in figure 16-12 with latitude to extract the value "Diff." Enter the table in figure 16-13 with the nearest longitude listed (do not interpolate) and the value "Diff" to extract the difference in minutes between the GMT of the phenomena at the Greenwich meridian and the LMT of the phenomena at the observer's meridian. These minutes are then applied (following the rules in figure 16-13) to the moonrise or moonset extracted from figure 16-12.



Lat.	Moon-rise	Diff.
N		
°	h m	m
72	■	*
70	■	*
68	■	*
66	■	*
64	17 53	-02
62	17 03	+12
60	16 32	16
58	16 08	17
56	15 49	19
54	15 33	19
52	15 20	20
50	15 08	21
45	14 43	21
40	14 23	22
35	14 06	23
30	13 52	23
20	13 27	24
10	13 06	24
0	12 46	25
10	12 26	26
20	12 05	26
30	11 40	27
35	11 26	27
40	11 09	28
45	10 49	28
50	10 23	29
52	10 11	29
54	09 57	30
56	09 40	30
58	09 21	31
60	08 56	32
S		

Lat.	Moon-set	Diff.
N		
°	h m	m
72	01 47	61
70	01 39	56
68	01 33	52
66	01 28	49
64	01 24	47
62	01 20	44
60	01 17	42
58	01 14	41
56	01 12	39
54	01 10	38
52	01 08	37
50	01 06	36
45	01 02	33
40	00 59	31
35	00 56	30
30	00 53	28
20	00 49	26
10	00 45	24
0	00 42	22
10	00 38	20
20	00 34	17
30	00 30	15
35	00 27	13
40	00 25	12
45	00 21	10
50	00 18	08
52	00 16	07
54	00 14	06
56	00 12	04
58	00 09	03
60	00 07	02
S		

Figure 16-12. Moonrise and Moonset

Example:

Find the LMT of moonrise at position 30°00′N, 133°00′W.

Step 1. GMT of moonrise at the Greenwich meridian is 1352 and Diff is +23 (figure 16-12).

Step 2. The interpolation table reflects a correction of +19 (figure 16-13).

Step 3. 1352 + 19 = 1411 LMT moonrise at the observer's position.

The LMT of moonrise at the observer's longitude can be converted to GMT of moonrise at the observer's longitude using the conversion of arc to time solution.

Sunlight and Moonlight Graphs

Graphs for the computation of sunrise or sunset and moonrise or moonset in high latitudes are also provided in the *Air Almanac.*

The Semiduration of Sunlight Graph, shown in figure 16-14, is entered with the date and latitude.

Add if Longitude west.
Subtract if Longitude east.

LONGITUDE	DIFF.*					
	05	10	15	20	25	30
°	m	m	m	m	m	m
0	00	00	00	00	00	00
20	01	01	02	02	03	03
40	01	02	03	04	06	07
60	02	03	05	07	08	10
80	02	04	07	09	11	13
100	03	06	08	11	14	17
120	03	07	10	13	[illegible]	20
140	04	08	12	16	19	23
160	04	09	13	18	[illegible]	27
180	05	10	15	20	25	30

LONGITUDE	DIFF.*					
	35	40	45	50	55	60
°	m	m	m	m	m	m
0	00	00	00	00	00	00
15	03	03	04	04	05	05
30	06	07	08	08	09	10
45	09	10	11	12	14	15
60	12	13	15	17	18	20
75	15	17	19	21	23	25
90	18	20	22	25	28	30
105	20	23	26	29	32	35
120	23	27	30	33	37	40
135	26	30	34	38	41	45
150	29	33	38	42	46	50
165	32	37	41	46	50	55
180	35	40	45	50	55	60

LONGITUDE	DIFF.*					
	65	70	75	80	85	90
°	m	m	m	m	m	m
0	00	00	00	00	00	00
10	04	04	04	04	05	05
20	07	08	08	09	09	10
30	11	12	12	13	14	15
40	14	16	17	18	19	20
50	18	19	21	22	24	25
60	22	23	25	27	28	30
70	25	27	29	31	33	35
80	29	31	33	36	38	40
90	32	35	38	40	42	45
100	36	39	42	44	47	50
110	40	43	46	49	52	55
120	43	47	50	53	57	60
130	47	51	54	58	61	65
140	51	54	58	62	66	70
150	54	58	62	67	71	75
160	58	62	67	71	76	80
170	61	66	71	76	80	85
180	65	70	75	80	85	90

*When negative *subtract* correction if Longitude west, and *add* if east.

Figure 16-13. Interpolation of Moonrise, Moonset, for Longitude

If date and latitude intersect on a curve, the value of the Semiduration of Sunlight curve indicates one-half of the sunlight for that day at that latitude. If the date and latitude intersect above the curved lines, continuous light or darkness exist. Directly above the date is the LMT of the sun's meridianal transit. To find the LMT of sunrise, subtract the semiduration of sunlight from the time of the sun's meridianal transit; for sunset, add the semiduration of sunlight to the time of meridian transit.

Example:

Find LMT of sunrise and sunset at latitude 80°N on 1 April 1966. The Semiduration of Sunlight Graph (figure 16-14) indicates the semiduration of sunlight to be 8^h and the time of meridian passage to be 12^h04^m. Therefore, the LMT of sunrise is 0404 ($12^h04^m - 8^h0^m$) and sunset is 2004 ($12^h04^m + 8^h0^m$).

The graph, Duration of Twilight (figure 16-15), gives the interval from the beginning of morning civil twilight (sun 6° below the horizon) to the time of sunrise, or from the time of sunset to the end of evening civil twilight. In the region "No twilight nor sunlight" the sun is continuously below the horizon by more than 6°. In the region "Continuous twilight or sunlight" the sun never goes lower than 6° below the horizon. Adjacent to the region of "No twilight nor sunlight" is a region in which the sun is continuously below the horizon, but so near to the horizon during a portion of the day that there is twilight. The value given by the graph in this region is the interval from the beginning of morning twilight to meridian passage of the sun, or from meridian passage to the end of evening twilight, the total duration of twilight being twice the value given by the graph.

Examples:

On 10 March at latitude 78°N, the Duration of Twilight Graph indicates the duration of twilight as about 1^h45^m. Applying this to the time of sunrise, 07^h25^m, the beginning of morning twilight is 05^h40^m LMT. At latitude 80°N there is no sunlight nor twilight till about 6 February. There is twilight but no sunlight from 6 February until 20 February; sunlight and twilight till 31 March; continuous twilight or sunlight till 15 April; and then continuous sunlight. At latitude 80°N on 14 February, duration of twilight is 3 hours. However, morning twilight and evening twilight occur as a continuous phenomena. Thus, BMT

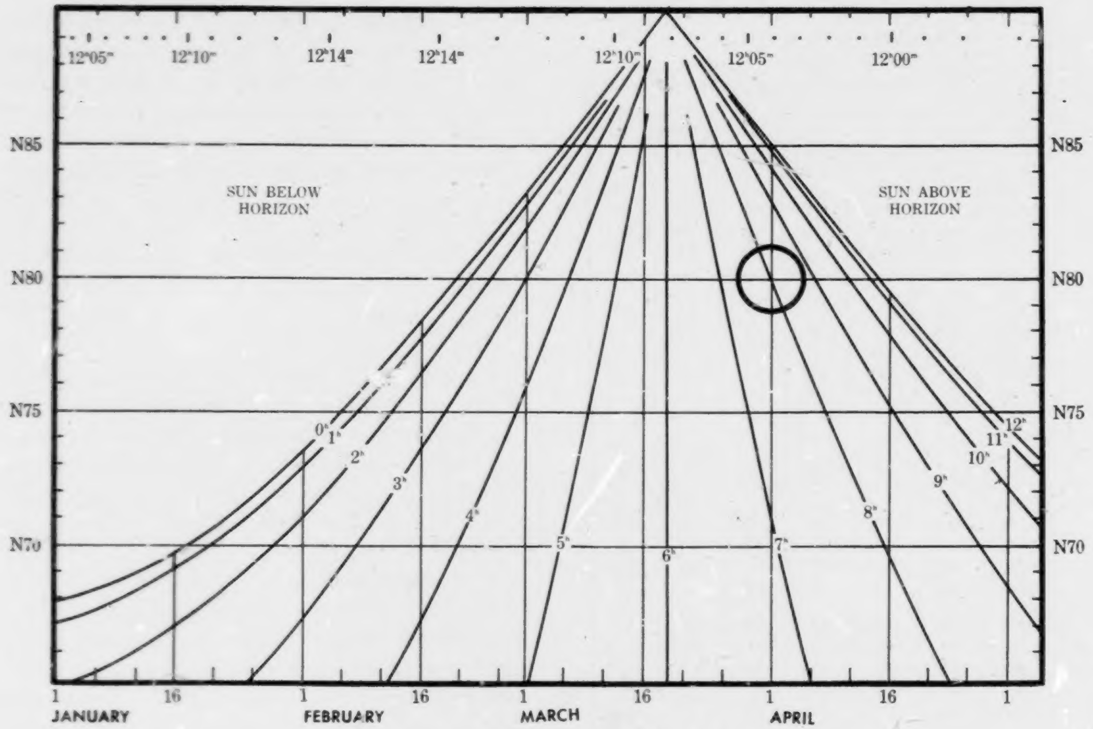


Figure 16-14. Semiduration of Sunlight

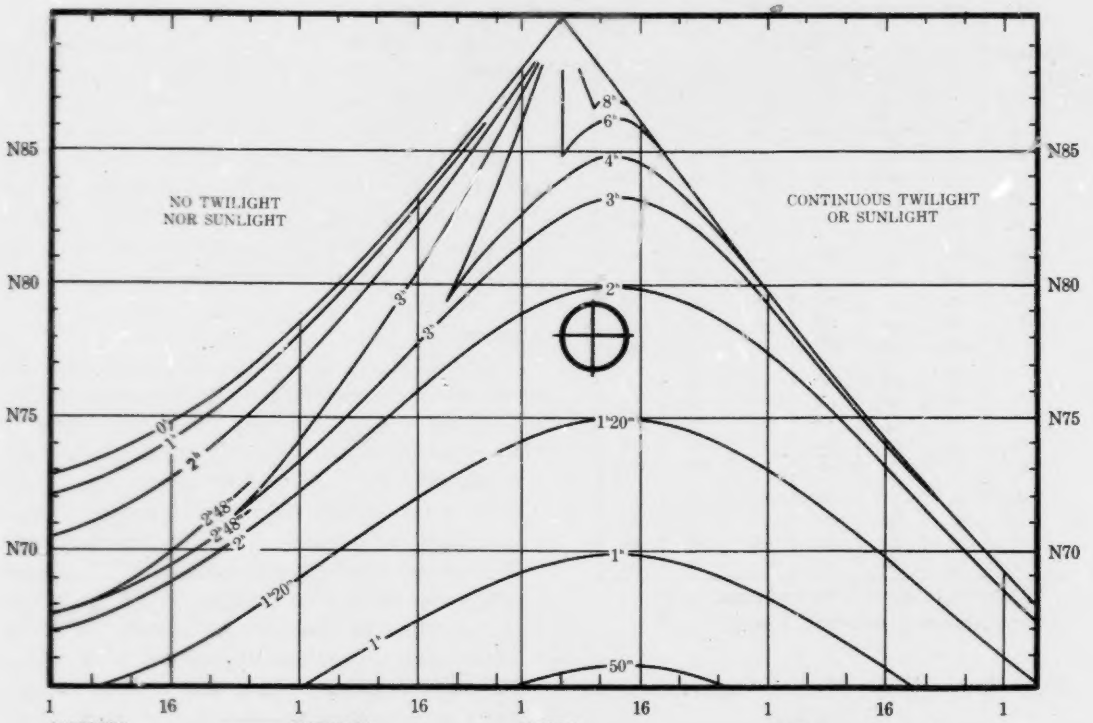


Figure 16-15. Duration of Twilight

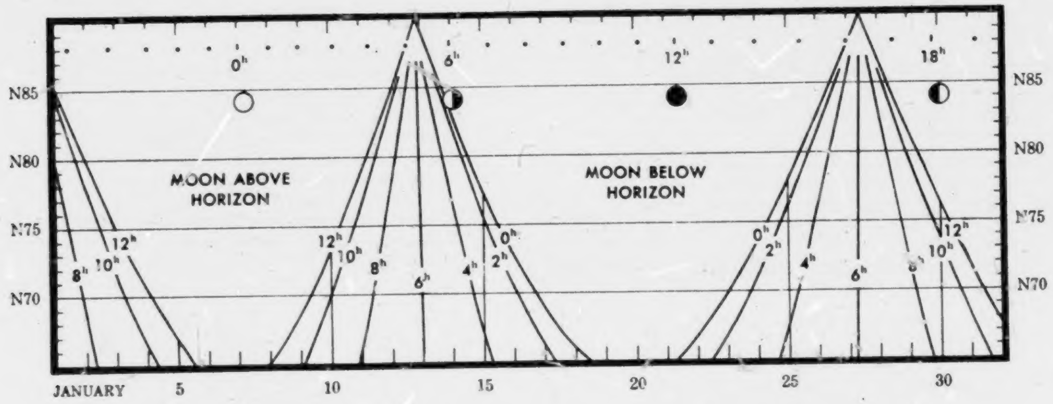


Figure 16-16. Semiduration of Moonlight

is 0914 LMT (1214 meridian passage — 3 hrs) and EET is 1514 LMT (1214 + 3 hrs).

The graphs, Semiduration of Moonlight (figure 16-16), give for the moon the same data as the graphs, Semiduration of Sunlight, give for the sun. The scales near the top give the LMT of meridian passage. The phase symbols on the graphs show the approximate date on which each phase occurs. Since the times of meridian passage and the semiduration change more rapidly from day to day for the moon than for the sun, special care is required in reading the graphs accurately.

TRUE HEADING BY CELESTIAL OBSERVATION

The periscopic sextant, in addition to measuring celestial altitudes, can be used to determine true headings and bearings. Any celestial body whose azimuth can be computed can be used to obtain a true heading. Except for Polaris, the appropriate volume of H.O. 249 is entered to obtain Zn (true bearing). In the case of Polaris the *Air Almanac* has an Azimuth of Polaris table and therefore does not require information from the H.O. 249 tables.

Three methods are used to obtain true heading with the periscopic sextant. Only the true bearing method requires precomputation of Zn. Post computation of Zn is possible with the relative bearing method and the inverse relative bearing method. The procedures are as follows:

True Bearing Method (TB)

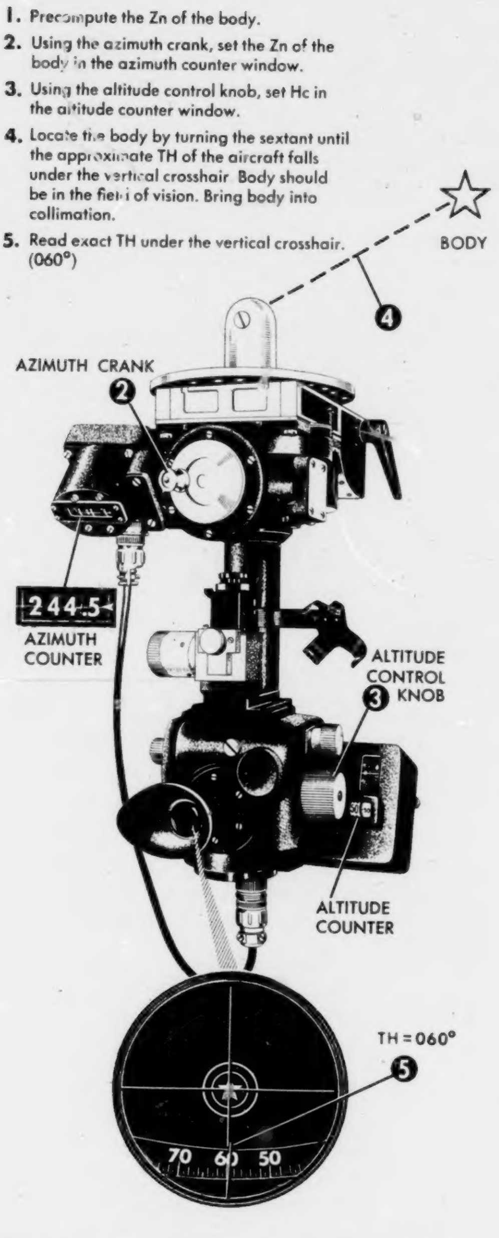
- Determine GMT and body to be observed.
- Extract GHA from the *Air Almanac*.
- Apply exact longitude to GHA to obtain LHA.
- Enter appropriate H.O. 249 table and extract Zn (true bearing) and Hc (figure 16-17). If Polaris is used, obtain the azimuth from the Azimuth of Polaris table in the *Air Almanac*, and use your latitude instead of Hc (figure 16-18).
- Set Zn in the azimuth counter window with the azimuth crank and set Hc in the altitude counter window with the altitude control knob.
- Collimate the body at the precomputed time and read the true heading of the aircraft under the vertical crosshair in the field of vision. If you are using precomputation techniques, a true heading is available every time an altitude observation is made.

Relative Bearing Method (RB)

- Bring the body into collimation.
- Turn the azimuth crank (and the sextant as necessary), until 0° is under the vertical crosshair in the field of vision.
- At the desired time read the relative bearing of the body in the azimuth counter window.
- Compute Zn (true bearing) of the body and use the formula: TH = TB — RB.

Inverse Relative Bearing Method (IRB)

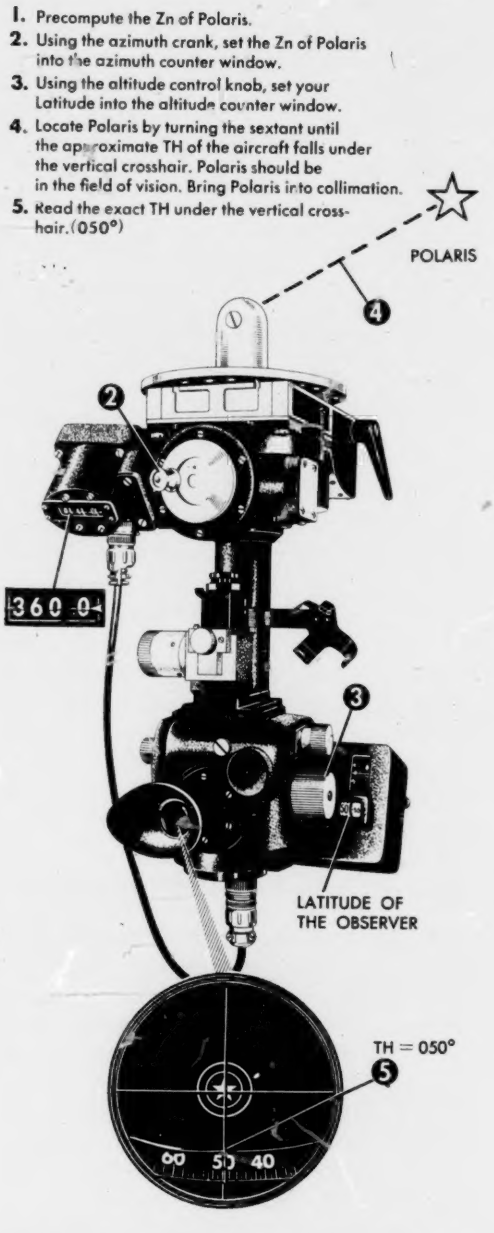
- Set 000° in the azimuth counter window with the azimuth crank (figure 16-19).
- Collimate the body. At the desired time, read the bearing (IRB) under the vertical crosshair in the field of vision.



1. Precompute the Zn of the body.
2. Using the azimuth crank, set the Zn of the body in the azimuth counter window.
3. Using the altitude control knob, set Hc in the altitude counter window.
4. Locate the body by turning the sextant until the approximate TH of the aircraft falls under the vertical crosshair. Body should be in the field of vision. Bring body into collimation.
5. Read exact TH under the vertical crosshair. (060°)

BODY
④
AZIMUTH CRANK
②
244.5
AZIMUTH COUNTER
ALTITUDE CONTROL
③ KNOB
ALTITUDE COUNTER
TH = 060°
⑤
70 60 50

Figure 16-17. True Bearing Method (Except Polaris)



1. Precompute the Zn of Polaris.
2. Using the azimuth crank, set the Zn of Polaris into the azimuth counter window.
3. Using the altitude control knob, set your Latitude into the altitude counter window.
4. Locate Polaris by turning the sextant until the approximate TH of the aircraft falls under the vertical crosshair. Polaris should be in the field of vision. Bring Polaris into collimation.
5. Read the exact TH under the vertical crosshair. (050°)

POLARIS
④
②
360.0
③
LATITUDE OF THE OBSERVER
TH = 050°
⑤
60 50 40

Figure 16-18. True Bearing Method (Using Polaris)

- Compute Zn of the celestial body and use the formula: TH = Zn + IRB.

Computing Zn for Heading Checks

More accuracy is needed when computing Zn's for heading determination than when computing Zn's for plotting LOPs. To obtain this accuracy, the entering arguments (latitude, LHA, and declination) are computed to the nearest half degree.

Example:

Given:	Position	31°08′N, 121°14′W
	GHA	190°41′
	Dec	S16°29′
Find:	Zn	

1. Turn crank until 000° is in the azimuth counter window.
2. Locate the body and bring into collimation.
3. Read IRB under the vertical crosshair.
4. Solve the formula: TH = Zn + IRB

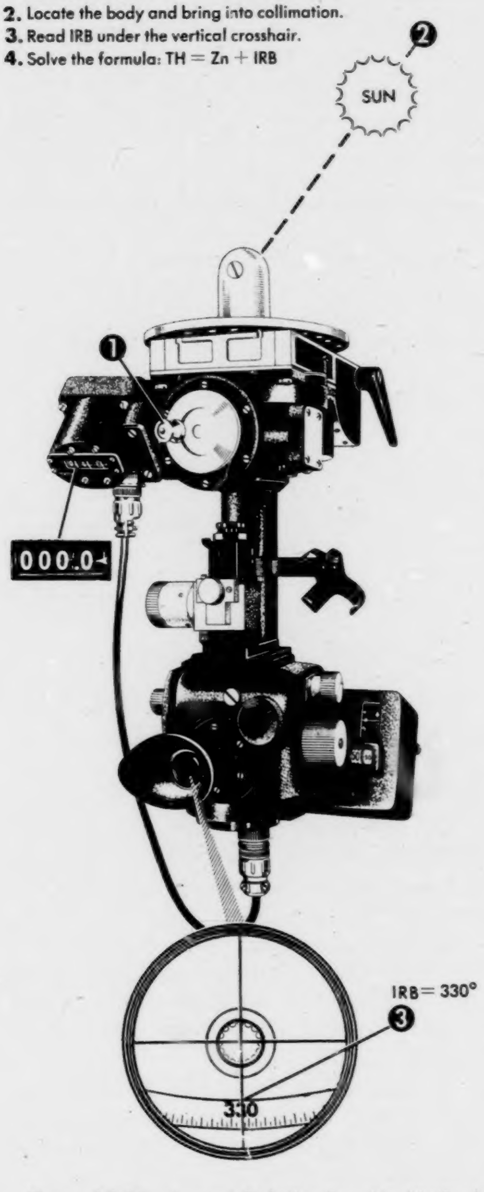


Figure 16-19. Inverse Relative Bearing Method

Solution:

Step 1. Compute the LHA (190°41′ — 121°14′ = 68°27′).

Step 2. Enter the slight reduction table, page LAT 31°, "Declination (15°-29°) Contrary Name to Latitude," with LHA 68° and 69° for declinations 16° and 17°. See figure 16-20.

Step 3. Interpolate between LHAs 68° and 69° under declinations 16° and 17° to obtain the correct Z (115½°).

Step 4. The position is in the Northern Hemisphere and the LHA is less than 180°; therefore, Zn = 360° — 115½° = 244½°.

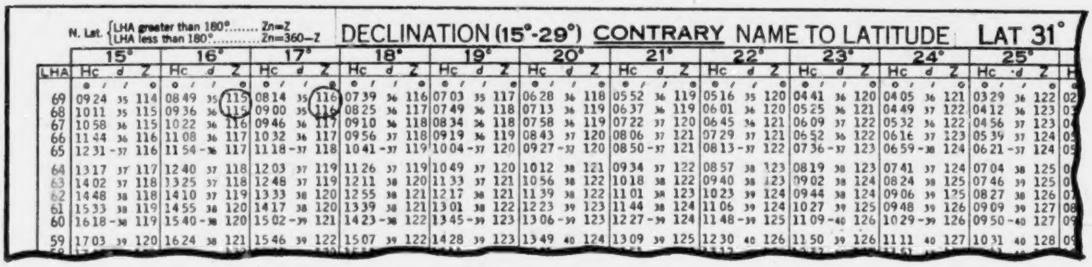
CELESTIAL NAVIGATION IN HIGH LATITUDES

Celestial navigation in polar regions is of primary importance because (1) it constitutes the principal method of determining position other than by dead reckoning, and (2) it provides the only means of establishing direction over much of the polar regions. The magnetic compass and directional gyro are useful in polar regions, but they require an independent check, which is provided only by celestial bodies. Celestial navigation is of such importance in polar regions that the navigator customarily devotes almost full time to it.

Timepieces should be given special care. They should be wound regularly and their errors checked by time signal before each flight. They should not be exposed to very low temperatures. Below approximately —40° (F or C), a precision watch becomes unreliable. A wristwatch receives sufficient heat from the body, but any other timepiece should be protected from severe temperatures. This may be done by keeping it in an inside pocket where it will be warmed by body heat. Even though a watch may be operating properly, its rate may be changed by a large change in temperature.

At high latitudes, the sun's daily motion is nearly parallel to the horizon. In areas of continuous sunlight the moment chosen as the start of the day is of little importance. Hence, GMT is customarily used for flights. The *motion of the aircraft* in these regions can easily have greater effect upon the altitude and true azimuth of the sun than the motion of the sun itself. At latitude 64°, an aircraft flying west at 400 knots keeps pace with the sun, which appears to remain stationary in the sky. At higher latitudes the altitude of a celestial body might be increasing at any time of day, if the aircraft is flying toward it, and a body might rise or not, at any azimuth, depending upon the direction of motion of the aircraft relative to the body.

Since the apparent motion of celestial bodies is nearly horizontal, and their azimuth relation-



N. Lat. {LHA greater than 180°....... Zn=Z
{LHA less than 180°............ Zn=360−Z

DECLINATION (15°-29°) CONTRARY NAME TO LATITUDE LAT 31°

	15°			16°			17°			18°			19°			20°		
LHA	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z
	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°
69	09 24	35	114	08 49	35	115	08 14	35	116	07 39	36	116	07 03	35	117	06 28	36	118
68	10 11	35	115	09 36	36	115	09 00	35	116	08 25	36	117	07 49	36	118	07 13	36	119
67	10 58	36	115	10 22	36	116	09 46	36	117	09 10	36	118	08 34	36	118	07 58	36	119
66	11 44	36	116	11 08	36	117	10 32	36	117	09 56	37	118	09 19	36	119	08 43	37	120
65	12 31	−37	116	11 54	−36	117	11 18	−37	118	10 41	−37	119	10 04	−37	120	09 27	−37	120
64	13 17	37	117	12 40	37	118	12 03	37	119	11 26	37	119	10 49	37	120	10 12	38	121
63	14 02	37	118	13 25	37	118	12 48	37	119	12 11	38	120	11 33	37	121	10 56	38	122
62	14 48	38	118	14 10	37	119	13 33	38	120	12 55	38	121	12 17	38	121	11 39	38	122
61	15 33	38	119	14 55	38	120	14 17	38	120	13 39	38	121	13 01	38	122	12 23	39	123
60	16 18	−38	119	15 40	−38	120	15 02	−39	121	14 23	−38	122	13 45	−39	123	13 06	−39	123
59	17 03	39	120	16 24	38	121	15 46	39	122	15 07	39	122	14 28	39	123	13 49	40	124

	21°			22°			23°			24°			25°		
LHA	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z
	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°
69	05 52	36	119	05 16	35	120	04 41	36	120	04 05	36	121	03 29	36	122
68	06 37	36	119	06 01	36	120	05 25	36	121	04 49	37	122	04 12	36	123
67	07 22	37	120	06 45	36	121	06 09	37	122	05 32	36	122	04 56	37	123
66	08 06	37	121	07 29	37	121	06 52	36	122	06 16	37	123	05 39	37	124
65	08 50	−37	121	08 13	−37	122	07 36	−37	123	06 59	−38	124	06 21	−37	124
64	09 34	37	122	08 57	38	123	08 19	38	123	07 41	37	124	07 04	38	125
63	10 18	38	122	09 40	38	123	09 02	38	124	08 24	38	125	07 46	39	125
62	11 01	38	123	10 23	39	124	09 44	38	124	09 06	39	125	08 27	38	126
61	11 44	38	124	11 06	39	124	10 27	39	125	09 48	39	126	09 09	39	127
60	12 27	−39	124	11 48	−39	125	11 09	−40	126	10 29	−39	126	09 50	−40	127
59	13 09	39	125	12 30	40	126	11 50	39	126	11 11	40	127	10 31	40	128

Figure 16-20. Interpolation of LHAs and Declinations for Heading Determination

ship changes relatively little, it is not unusual for the same celestial bodies to be used for successive fixes throughout a flight in polar regions.

Observations can be made by the same instruments and techniques as in lower latitudes. However, a periscopic sextant is most suitable for polar regions because (1) it can be used for both altitude observations and heading checks, (2) it is easier to use for low altitudes often required during summer, and avoids large and uncertain astrodome refraction, and (3) it avoids the problem of astrodome fogging, when the outside temperature is very low.

Bodies Available for Observation

During the continuous daylight of the polar summer only the sun is regularly available for observation. The moon is above the horizon about half the time, but generally it is both visible and at a favorable position with respect to the sun for only a few days each month.

During the long polar twilight, no celestial bodies may be available for observation by an ordinary sextant, although directional guidance can be obtained by means of a sky compass. As in lower latitudes, the first celestial bodies to appear after sunset and the last to remain visible before sunrise are those brighter planets which are above the horizon. Usually, a bright planet is visible throughout the twilight period, so that no break in routine need occur. Good advance flight planning can do much to avoid long periods without observations.

The sun, moon, and planets are never high in polar skies. Low altitude observations are routine, for often they are the only ones available. Particularly with the sun, observations are made whenever any part of the body is visible. If it is partly below the horizon, the upper limb is observed, and a correction of −16′ for semidiameter is applied to the sextant altitude.

During the polar night, stars are available. Polaris is not generally used because it is too near the zenith in the arctic and not visible in the antarctic. A number of good stars are in favorable positions for observation. Because of large and somewhat unpredictable refraction in polar regions, particularly near the horizon, low altitudes (below about 20°) are avoided when higher bodies are visible.

Sight Reduction

Sight reduction in polar regions presents some slightly different problems from those at lower latitudes. Since low altitude observations are common, H.O. 249 is the most suitable method for continuous use, because it provides for altitudes down to the visible horizon at flight altitudes. Polar flights are often of long duration, and the busy navigators are usually quite fatigued near the end of the flight. An easy method, such as provided by H.O. 249, which offers less opportunity for a blunder, is desirable under these conditions.

For latitudes greater than 69° N or 69° S, H.O. 249 tables have tabulated Hc's and azimuths for only even degrees of LHA. This concerns the navigator in two ways:

1. It is necessary to select an assumed position at the nearest longitude, where the LHA is an even degree; for example, GHA 195°15′, DR position 75°17′N, 98°20′W. Using an assumed longitude of 98°15′W would result in LHA of 97°00′. H.O. 249 does not list an LHA of 97° for this latitude. Changing the assumed longitude to 97°15′W or 99°15′W, will give an LHA listed in the H.O. 249 table.
2. The difference between successive tabulated

Hc's is for 2 degrees of LHA, or eight minutes of time, and this difference must be divided in half when computing motion of the body for four minutes of time.

For ease of plotting, all azimuths can be converted to grid. In this connection, the longitude of the assumed position should be used to determine convergence—since the tabulated azimuth is for the assumed position, not the DR position. On polar charts, convergence is equal to longitude.

In computing motion of the observer, it is imperative that the navigator use the difference between grid azimuth and grid track, since this computation is based on relative bearings. True azimuth minus grid course does not give relative bearing. This latter is a common source for error in computing motion of the observer.

In lower latitudes some navigators avoid observation of celestial bodies near the horizon and ignore the refraction correction. Since low altitudes are frequently used in polar regions, the high latitude navigator should form the habit of referring to the refraction correction table for all observations to avoid overlooking it when needed. Because low temperatures are not unusual in polar regions, the use of the temperature correction factor should be considered for all observations.

In polar regions Coriolis corrections reach maximum values and should not be overlooked.

Poles as Assumed Positions

Within approximately two degrees of the pole, it is possible to use the pole as the assumed position. With this method, no tabulated celestial computation is necessary, and the position may be determined by use of the *Air Almanac* alone.

At either of the poles of the earth, the zenith and the elevated poles are coincident, and the plane of the horizon is coincident with the plane of the equator. Vertical circles coincide with the meridians and parallels of latitude coincide with declination circles. Therefore, the altitude of the body is equal to its declination, and the azimuth equal to its hour angle.

To plot any LOP, an intercept and the azimuth of the body are needed. In this solution, the elevated pole is the assumed position. The azimuth is plotted as the GHA of the body, or the longitude of the subpoint. The intercept is found by comparing the declination of the body, as taken from the *Air Almanac*, with the observed altitude of the body. To summarize, the pole is the assumed position, the declination is the Hc, and the GHA equals the azimuth.

For ease of plotting, convert the GHA of the body to grid azimuth by adding or subtracting 180° when using the North Pole as the assumed position. When at the South Pole, 360° — GHA of the body equals grid azimuth. The result will allow the use of the grid lines for plotting the LOPs. When using grid azimuth for plotting, apply Coriolis to the assumed position (in this case the pole). Precession/nutation corrections are not necessary since current SHA and declination are used. Motion of the observer tables may also be used in precomputation, since grid azimuth relative to grid course may be determined. Motion of the body is zero at the poles.

When a celestial body is observed, note the exact GMT. From the almanac, extract the proper declination and GHA. Plot the azimuth. Compare Ho and Hc to obtain the intercept. When the observed altitude, Ho, is greater than the declination, Hc, it is necessary to go from the pole toward the celestial body along the azimuth. If the observed altitude is less than the declination, as is the case with the sun in figure 16-21 it is necessary to go from the pole away from the body along the azimuth. Draw the LOPs perpendicular to the azimuth line in the usual manner. It is not necessary to be concerned about large intercepts; they

SUN		MOON	
H_c (DEC)	23°12′N	H_c (DEC)	10°57′N
H_o	22°04′	H_o	9°56′
INTERCEPT	68 NM AWAY	INTERCEPT	61 NM AWAY
GHA	168	GHA	236
	+180		−180
Grid ZN	348	GRID ZN	056

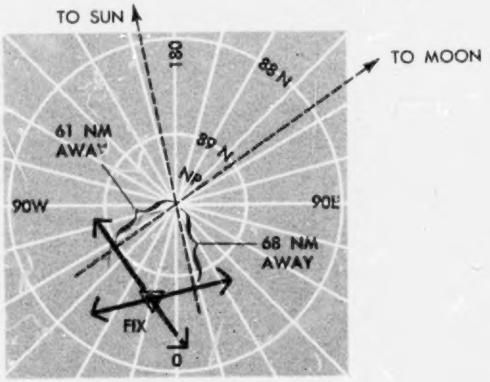


Figure 16-21. Using Pole as Assumed Position

have no bearing on the accuracy of this type of fix. Observations on well-separated bearings give a fix that is as good close to the pole as it is anywhere else.

Use of Periscopic Sextant

The periscopic sextant may be used for heading checks in the polar regions in much the same manner as it is used at lower latitudes. The periscopic sextant is less subject to errors caused by inaccurate mounting, one correction for azimuth readings applies to all bearings, and there is no problem of dome refraction error when sighting on bodies at low altitudes. The major disadvantage in its use for computing grid headings in the manner to be described is that it will cause any error in DR position for the heading to be reflected in the grid heading.

Use the periscopic sextant to obtain grid headings in the following manner:

Step 1. Obtain the azimuth of the celestial body by H.O. 249 solution and apply the longitude or convergence angle (+West, —East) to the true azimuth to obtain grid azimuth.

Step 2. Set the azimuth in the azimuth counter of the sextant.

Step 3. Collimate the body and read the grid azimuth directly under the vertical crosshair of the azimuth scale, which is visible through the eyepiece.

NOTE: A heading check may be taken during regular celestial shots with the periscopic sextant. If regular shots are taken at hourly intervals, for example, the grid azimuth for the half hour heading check can be computed at the same time as the celestial precomputations are made.

SUMMARY

Although the special celestial techniques covered in this chapter are generally used when unique situations are encountered, some navigators favor and use them as routine. Latitude by Polaris results in a shorter solution time. The navigator figures time of sunset on day/night flights, and usually adopts one of the three methods of true heading determination not only because of personal preference but because of conditions dictated by such factors as weather or area.

CHAPTER 17

Celestial Precomputation

Celestial precomputation is neither new nor revolutionary. Actually, the tables necessary to do precomputation have been available since 1940, but the real need for precomputation was not then present. With high-speed aircraft, however, the picture has changed radically. By the methods previously discussed, it is apparent that a great deal of work is accomplished after the last celestial observation is taken. The fix could easily be 10 to 20 minutes old, depending on the speed and proficiency of the navigator, at the time it is plotted on the chart. At a 600-knot groundspeed, a fix that is 15 minutes old is 150 miles behind the aircraft and is of questionable value. The need now exists to shorten the time between the last celestial observation and the final fix plotted on the chart.

Another reason why precomputation is needed in high-speed aircraft lies in the very structure of the aircraft itself. There can be no projections such as an astrodome on these aircraft. The navigator will probably be using a periscopic sextant which could easily be his only means of viewing the heavens. With the limited field of vision of the sextant, the star would be extremely difficult to find in the optics if he did not know where to look.

PRESETTING THE SEXTANT

Precomputation greatly reduces both of the problems just mentioned. By completing most of the computations before shooting, the navigator can greatly reduce the time necessary to plot the fix after the last observation. Also the problem of finding the star in the optics of the sextant is simplified. The procedure for finding the star is very similar to the heading check performed with the periscopic sextant, using the true bearing method as explained in Chapter 16. In this case the Zn, known beforehand, is set into the sextant mount, and the Hc, which will approximate the Hs, is set into the sextant. Now, instead of sighting the body and determining the true heading, the true heading is set under the vertical crosshair and the selected body is found very close to the crosshairs in the sextant field of vision.

To avoid erroneous settings of the azimuth window and to increase speed in setting up the sextant, the relative bearing method may be used. In this method the azimuth window remains permanently at 360.0°, and the inverse relative bearing is computed by the formula IRB = TH − Zn. The body sought will be found at its computed altitude when its IRB appears under the crosshairs.

PRECOMPUTATION TECHNIQUES

There are many acceptable methods of precomputation in general usage. However, these methods are basically either graphical, mathematical, or a combination of graphical and mathematical. The method used by the practicing navigator will largely be determined by the type and speed of the aircraft, and by the type of mission flown.

Previously discussed celestial corrections which are used in precomputation include atmospheric and dome refraction, parallax of the moon, instrument and acceleration errors, coriolis and rhumb line, precession and nutation, motion of the observer, and wander. With precomputation, new corrections and terminology are introduced which include fix time, solution time, observation time, scheduled time, and motion of the body adjustment.

Fix time is the time for which the LOPs are resolved and plotted on the chart. *Solution time* is the time for which the astronomical triangle is solved. *Observation time* is the midtime of the actual observation for each celestial body. *Scheduled time* is the time for which the astronomical triangle is solved for each LOP in the graphical method. *Motion of the body correction* is used to correct for the changing altitude of the selected bodies, and can be applied either graphically or mathematically.

Motion of the Body Correction

Motion of the body correction is applied graphically by moving the assumed position eastward or westward for time. This is possible because the GHA of Aries, and consequently the subpoint of the body, moves westward at the rate of 1° of longitude per four minutes of time. In the graphical method a scheduled time of observation is given to each body. If shooting is off schedule, the following rules apply: For every minute of time that the shot is taken early, move the assumed position 15′ of longitude to the east; for every minute of time that the shot is taken late, move the assumed position 15′ of longitude to the west.

When the latitude of the assumed position and the Zn of the body are known, the motion of the body can be computed mathematically. For one minute the formula is: 15′ × cos lat × sin Zn. This correction has been computed and is shown in tabular form (figure 17-1).

If this table is not available to the navigator,

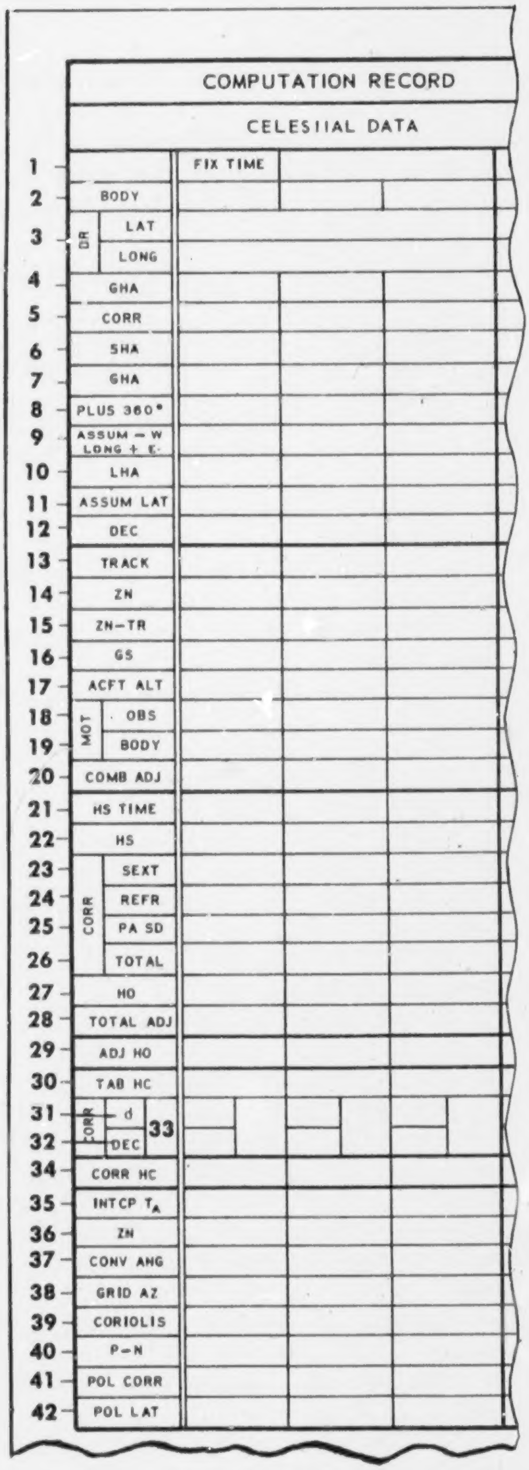
True Zn	Correction for 4 Minutes of Time																											True Zn
	Latitude																											
	0°	8°	16°	20°	24°	28°	30°	32°	34°	36°	38°	40°	42°	44°	46°	48°	50°	52°	54°	56°	60°	64°	68°	72°	76°	80°	84°	
°	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	°
090	+60	+59	+58	+56	+55	+53	+52	+51	+50	+49	+47	+46	+45	+43	+42	+40	+39	+37	+35	+34	+30	+26	+22	+19	+15	+10	+6	090
095	60	59	57	56	55	53	52	51	50	48	47	46	44	43	42	40	38	37	35	33	30	26	22	18	14	10	6	085
100	59	59	57	56	54	52	51	50	49	48	47	45	44	43	41	40	38	36	35	33	30	26	22	18	14	10	6	080
105	58	57	56	54	53	51	50	49	48	47	46	44	43	42	40	39	37	36	34	32	29	25	22	18	14	10	6	075
110	56	56	54	53	52	50	49	48	47	46	44	43	42	41	39	38	36	35	33	32	28	25	21	17	14	10	6	070
115	54	54	52	51	50	48	47	46	45	44	43	42	40	39	38	36	35	33	32	30	27	24	20	17	13	9	6	065
120	+52	+51	+50	+49	+47	+46	+45	+44	+43	+42	+41	+40	+39	+37	+36	+35	+33	+32	+31	+29	+26	+23	+19	+16	+13	+9	+5	060
125	49	49	47	46	45	43	43	42	41	40	39	38	37	35	34	33	32	30	29	27	25	22	18	15	12	9	5	055
130	46	46	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	28	27	26	23	20	17	14	11	8	5	050
135	42	42	41	40	39	37	37	36	35	34	33	33	32	31	29	28	27	26	25	24	21	19	16	13	10	7	4	045
140	39	38	37	36	35	34	33	33	32	31	30	30	29	28	27	26	25	24	23	22	19	17	14	12	9	7	4	040
145	34	34	33	32	31	30	30	29	29	28	27	26	26	25	24	23	22	21	20	19	17	15	13	11	8	6	4	035
150	+30	+30	+29	+28	+27	+26	+26	+25	+25	+24	+24	+23	+22	+22	+21	+20	+19	+18	+18	+17	+15	+13	+11	+9	+7	+5	+3	030
155	25	25	24	24	23	22	22	22	21	21	20	19	19	18	18	17	16	16	15	14	13	11	9	8	6	4	3	025
160	21	20	20	19	19	18	18	17	17	17	16	16	15	15	14	14	13	13	12	11	10	9	8	6	5	4	2	020
165	16	15	15	15	14	14	13	13	13	13	12	12	12	11	11	10	10	10	9	9	8	7	6	5	4	3	2	015
170	10	10	10	10	10	9	9	9	9	8	8	8	8	7	7	7	7	6	6	6	5	5	4	3	3	2	1	010
175	+5	+5	+5	+5	+5	+5	+5	+4	+4	+4	+4	+4	+4	+4	+4	+3	+3	+3	+3	+3	+3	+2	+2	+2	+1	+1	+1	005
180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	000
185	−5	−5	−5	−5	−5	−5	−5	−4	−4	−4	−4	−4	−4	−4	−4	−3	−3	−3	−3	−3	−3	−2	−2	−2	−1	−1	−1	355
190	10	10	10	10	10	9	9	9	9	8	8	8	8	7	7	7	7	6	6	6	5	5	4	3	3	2	1	350
195	16	15	15	15	14	14	13	13	13	13	12	12	12	11	11	10	10	10	9	9	8	7	6	5	4	3	2	345
200	21	20	20	19	19	18	18	17	17	17	16	16	15	15	14	14	13	13	12	11	10	9	8	6	5	4	2	340
205	25	25	24	24	23	22	22	22	21	21	20	19	19	18	18	17	16	16	15	14	13	11	9	8	6	4	3	335
210	30	30	29	28	27	26	26	25	25	24	24	23	22	22	21	20	19	18	18	17	15	13	11	9	7	5	3	330
215	−34	−34	−33	−32	−31	−30	−30	−29	−29	−28	−27	−26	−26	−25	−24	−23	−22	−21	−20	−19	−17	−15	−13	−11	−8	−6	−4	325
220	39	38	37	36	35	34	33	33	32	31	30	30	29	28	27	26	25	24	23	22	19	17	14	12	9	7	4	320
225	42	42	41	40	39	37	37	36	35	34	33	33	32	31	29	28	27	26	25	24	21	19	16	13	10	7	4	315
230	46	46	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	28	27	26	23	20	17	14	11	8	5	310
235	49	49	47	46	45	43	43	42	41	40	39	38	37	35	34	33	32	30	29	27	25	22	18	15	12	9	5	305
240	52	51	50	49	47	46	45	44	43	42	41	40	39	37	36	35	33	32	31	29	26	23	19	16	13	9	5	300
245	−54	−54	−52	−51	−50	−48	−47	−46	−45	−44	−43	−42	−40	−39	−38	−36	−35	−33	−32	−30	−27	−24	−20	−17	−13	−9	−6	295
250	56	56	54	53	52	50	49	48	47	46	44	43	42	41	39	38	36	35	33	32	28	25	21	17	14	10	6	290
255	58	57	56	54	53	51	50	49	48	47	46	44	43	42	40	39	37	36	34	32	29	25	22	18	14	10	6	285
260	59	59	57	56	54	52	51	50	49	48	47	45	44	43	41	40	38	36	35	33	30	26	22	18	14	10	6	280
265	60	59	57	56	55	53	52	51	50	48	47	46	44	43	42	40	38	37	35	33	30	26	22	18	14	10	6	275
270	−60	−59	−58	−56	−55	−53	−52	−51	−50	−49	−47	−46	−45	−43	−42	−40	−39	−37	−35	−34	−30	−26	−22	−19	−15	−10	−6	270

Observations Earlier than Solution Time - SIGNS AS GIVEN
Observations Later than Solution Time - SIGNS REVERSED

Figure 17-1. Correction for Motion of the Body

the correction may be easily determined in H.O. 249. For any stationary position (the assumed position), the LHA increases 1° every four minutes of time. Then the Hc in H.O. 249, for an LHA 1° less than the LHA used for precomputation, is the Hc for four minutes of time earlier than the solution time. The difference between the two Hc's is the value to apply to the Hc or Hs to advance or retard the LOP for four minutes of time. If the Hc decreases, the body is setting and the sign is minus to advance the LOP if the value is applied to the Hs. If the Hc increases, the body is rising and the sign is plus to advance the LOP if the value is applied to the Hs.

The main difference between the basic methods of precomputation is the manner in which the motion of the observer and the motion of the body corrections are applied. In the graphical method, both corrections are applied graphically by movement of the assumed position or the LOP. In the mathematical method, both corrections are applied mathematically to the Hc, the Hs, or the intercept after being obtained from tables or the H.O. 249.



COMPUTATION RECORD

CELESTIAL DATA

1			FIX TIME
2		BODY	
3	DR	LAT	
		LONG	
4		GHA	
5		CORR	
6		SHA	
7		GHA	
8		PLUS 360°	
9		ASSUM – W LONG + E	
10		LHA	
11		ASSUM LAT	
12		DEC	
13		TRACK	
14		ZN	
15		ZN–TR	
16		GS	
17		ACFT ALT	
18	MOT	OBS	
19		BODY	
20		COMB ADJ	
21		HS TIME	
22		HS	
23	CORR	SEXT	
24		REFR	
25		PA SD	
26		TOTAL	
27		HO	
28		TOTAL ADJ	
29		ADJ HO	
30		TAB HC	
31	CORR	d	33
32		DEC	
34		CORR HC	
35		INTCP T_A	
36		ZN	
37		CONV ANG	
38		GRID AZ	
39		CORIOLIS	
40		P–N	
41		POL CORR	
42		POL LAT	

Figure 17-2. Celestial Computation (Part of AF Form 21)

Celestial Section of AF Form 21

The celestial section of AF Form 21, Navigator's Log, provides space to facilitate celestial computations. To meet specialized operational requirements, major commands may prescribe and issue additional or substitute celestial precomputation forms. The numbers on the left margin of figure 17-2 are used to simplify the following explanations and are not found on AF Form 21:

1. FIX TIME. Place the Greenwich mean time of the computation in this block.

2. BODY. The celestial body being observed.

3. DR LAT LONG. The DR position for the time of the observation.
4. GHA. The value of GHA extracted from the *Air Almanac* (10 minute intervals).
5. CORR. This is the GHA correction for additional minutes of time to be applied to the GHA in block 4.
6. SHA. When a star is used in conjunction with Volumes II or III, H.O. 249, SHA is placed in this block.
7. GHA. This block contains a sum of the values of blocks 4, 5, and 6.
8. PLUS 360°. When in west longitude of greater

numerical value than block 7, block 8 will be the sum of block 7 and 360.

9. ASSUM — W The assumed longitudinal value
LONG + E
which renders the LHA a whole degree value.

10. LHA. LHA of the body (or Aries).

11. ASSUM LAT. The whole degree of latitude nearest the DR position.

12. DEC. The declination of the celestial body (not used with Volume I, H.O. 249).

13. TRACK. The track of the aircraft.

14. Zn. The Zn of the celestial body extracted from H.O. 249.

15. ZN-TR. The difference between Zn and track. (It is immaterial whether Zn is subtracted from track or vice versa.)

16. GS. The groundspeed of the aircraft.

17. ACFT ALT. Aircraft altitude.

18. MOT. OBS. Motion of the observer for four minutes of time (explained in Chapter 14).

19. MOT. BODY. Motion of the body for four minutes of time.

20. COMB ADJ. An algebraic sum of blocks 18 and 19.

21. HS TIME. The midtime of the observation.

22. HS. Height shot (sextant reading).

23. CORR SEXT. Sextant correction.

24. REFR. Correction for atmospheric refraction. If an astrodome is used, algebraically add the corrections for atmospheric and astrodome refractions.

25. PA SD. Parallax and semidiameter. Algebraically add PA and SD.

26. TOTAL. The algebraic sum of blocks 23, 24, and 25.

27. HO. Algebraic sum of blocks 22 and 26.

28. TOT ADJ. Correction, based on block 20, for the difference between the time of the shot and fix time. The sign of this correction will be the same as the sign in block 20 if the sextant observation was taken prior to the computation time; if it was taken later, the sign will be reversed.

29. ADJ HO. The algebraic sum of blocks 27 and 28.

30. TAB HC. Hc extracted from H.O. 249 tables.

31. "d". The value "d" listed beside the tabulated Hc in H.O. 249, Volumes II or III.

32. DEC. Minutes of declination from block 12.

33. CORR. The space beside block 31 and 32 is for the correction obtained from the "Correction to Tabulated Altitude for Minutes of Declination" table in Volumes II and III, H.O. 249.

34. CORR HC. The algebraic sum of blocks 30 and 33.

35. INTCP $^{T}{}_{A}$. Intercept distance (NM) toward or away is the difference between lines 29 and 34.

36. Zn. Same as block 14.

37. CONV ANG. Convergence angle used in grid navigation.

38. GRID AZ. Grid Zn (the sum of blocks 36 and 37).

39. Coriolis. The Coriolis correction extracted from H.O. 249 or the *Air Almanac*.

40. P - N. Precession and nutation correction computed from the table in Volume I, H.O. 249.

41. POL CORR. The "Q" correction for the time of the Polaris observation (extracted from H.O. 249 or the *Air Almanac*).

42. POL LAT. The navigator's latitude determined by applying block 41 to block 29.

Corrections Applied to Hc

In some methods of precomputation, corrections are applied in advance to the Hc to derive an adjusted Hc (sometimes referred to as Hp). When using corrections which are normally applied to Hs, the signs of the corrections are reversed if applied to Hc. For example:

Corrections Applied to Hs

Hs	31°05′
Atmosphere Refraction Correction	—01′
Sextant Correction	—05′
Ho	30°59′
Hc	30°40′
Intercept towards	19′

Corrections Applied to Hc

Hc	30°40′
Atmosphere Refraction Correction	+01′
Sextant Correction	+05′
Adjusted Hc (Hp)	30°46′
Hs	31°05′
Intercept towards	19′

In both cases the intercept is 19′ towards. This example shows that it matters little in which manner observational errors are taken into account. As long as they are applied with the proper sign, the intercept remains the same.

Limitations of Precomputation

Precomputational methods lose accuracy when the assumed position and the aircraft's actual position differ by large distances. Another limiting factor is the difference in time between the scheduled and actual observation time. The motion of the body correction is intended to correct for this difference.

The rate of change of the correction for motion of the body changes very slowly within 40° of 090° and 270° true azimuth, and the observation can be advanced or retarded for a limited period of time with little or no error. When the body is near the observer's meridian, the correction for motion of the body changes rapidly, due in part to the fast azimuth change, and it is not advisable to adjust such observations for long periods of time.

Errors in altitude and azimuth creep into the solution if adjustments are made for too long an interval of time. Because of these errors, the navigator should try to keep his scheduled and actual observation times as close as possible.

SPECIAL PLOTTING TECHNIQUES

There are several plotting techniques which work especially well with celestial precomputation, although they are not restricted to this type of sight reduction. The two primary plotting techniques are preplotting the Zn's and plotting the fix on the DR computer.

Preplotting True Azimuth (Zn's)

This technique is best used when working on a constant scale chart and using some technique of precomputation that will give one assumed position. Set up the procedure on the chart by plotting (prior to observations) the assumed position and through this point, the Zn's of the bodies. When going toward the body, use a solid line or a colored pencil, and when going away from the body use a dashed line or a different colored pencil. Label each Zn as the 1st, 2nd, or 3rd as shown in figure 17-3, or use the names of the stars. If desired, distances from the assumed position can also be marked off. Suppose the corrected assumed position is 30°40′N, 117°10′W and the following Zn's were computed for the bodies:

1st Shot Zn = 020°
2nd Shot Zn = 135°
3rd Shot Zn = 270°.

(The original assumed position of 31°N, 117°08′W has been corrected for precession/nutation and for Coriolis/rhumb line error to get the corrected assumed position.)

When the first intercept is found to be 10A, second intercept 40A, and the third 50T, the fix can be plotted quickly by constructing perpendicular lines at the correct point on the respective *Zn line*. No direction or distance measurement is required after shooting—only the intercept is needed. This greatly reduces the time necessary to plot the fix. Since the dashed part of the Zn line is the away situation, it is used for the first two intercepts; while the solid or toward situation, is used for the third intercept.

Plotting Fix on DR Computer

The following examples explain the procedures for plotting the fix on the DR computer. This technique is especially favored by units flying in high-speed aircraft where plotting time must be kept to a minimum. It can be used effectively to plot a fix in any situation.

To plot the LOPs on the DR computer, the square grid portion is used exclusively. The grommet of the DR computer is the assumed position and is assigned a definite value of *both latitude and longitude*. Where the same assumed position is used for all three shots, the co-ordinates of the assumed position are the assigned values.

The Zn of the first shot is placed under the true index. If the intercept is toward, it is measured above the grommet. The LOP is then constructed by drawing a perpendicular through this point. If the intercept is away, intercept distance is measured below the grommet, and the perpendicular is constructed for the LOP.

In a Polaris shot, 360° is placed under the true index and the LOP is plotted above the grommet if the latitude determined is greater than the assigned latitude value of the grommet, and below if the Polaris latitude is less than the as-

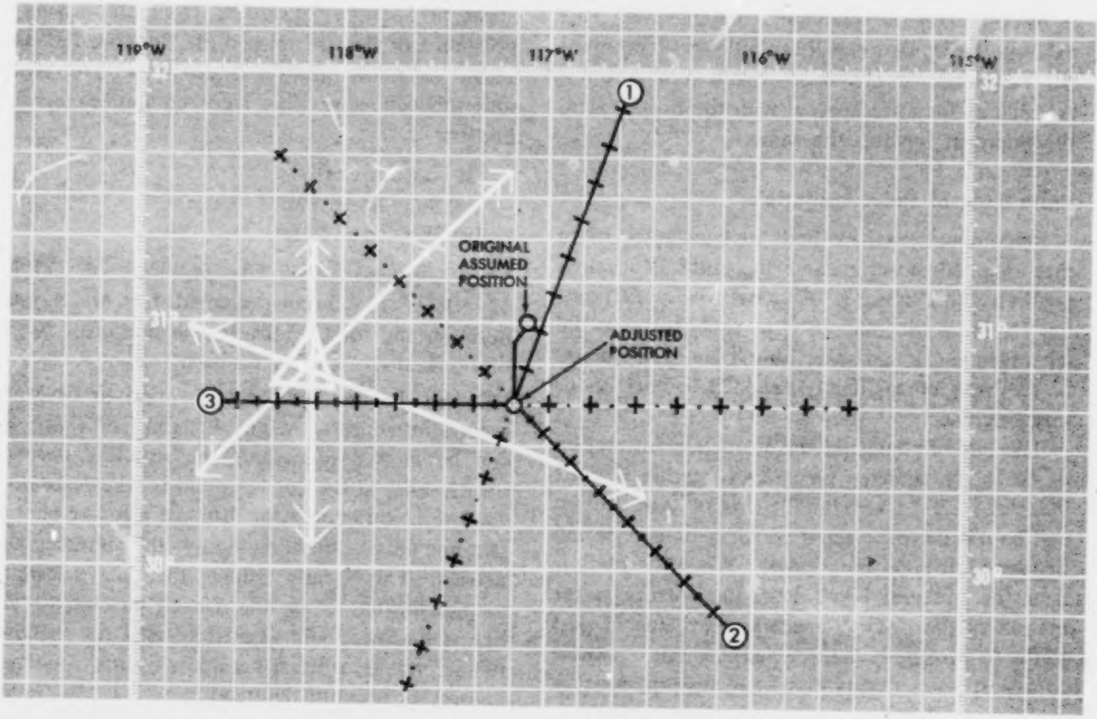


Figure 17-3. Fix Can be Plotted Quickly

signed value of latitude. The distance above or below the grommet in the case of Polaris is the same number of nautical miles as the difference in minutes between the latitude assigned to the grommet and the Polaris latitude. This is true because one minute of latitude is one nautical mile.

The three LOPs plotted as above constitute the uncorrected fix. Precession/nutation if using Volume I of H.O. 249 and Coriolis/rhumb line correction is then applied to this uncorrected fix. The final fix is then placed vertically *above* the grommet to obtain the range and bearing of the fix *from* the grommet. This is also the range and bearing of the final fix from the latitude and longitude previously assigned to the grommet. The fix is plotted on the chart using this range and bearing from the latitude and longitude originally assigned to the grommet of the computer.

Sample Problem

A step-by-step procedure for a sample problem is shown in figure 17-4. The assumed position for two of the shots (moved up to a common time) is 31°00′N, 90°18′W; the other shot is on Polaris. The track is 118° and the Coriolis/rhumb line correction is 10 nautical miles to the right. Precession/nutation correction is 3NM/290°. The Polaris shot was taken first and corrected to a latitude value of 31°23′N. The second shot, Sirius, has a Zn of 231° and an intercept of 6 away. The third shot was taken on Spica; the Zn is 122° and the intercept 21 away.

1. Place 360° (N) under the true index and draw in the Polaris LOP, 23 nautical miles above the grommet.
2. Place 231° under the true index and draw in the Sirius LOP, 6 NM below the grommet (6A).
3. Place 122° under the true index and draw in the Spica LOP, 21 NM below the grommet (21A).
4. Place 290° under the true index and go up 3 nautical miles from the *uncorrected fix* to take care of the precession/nutation correction. Go up because the values of the precession/nutation correction indicate that the fix is to be moved 3 nautical miles in the direction of, or towards, 290°.
5. Place the track (118°) under the true index and go 10 nautical miles *to the right* from the

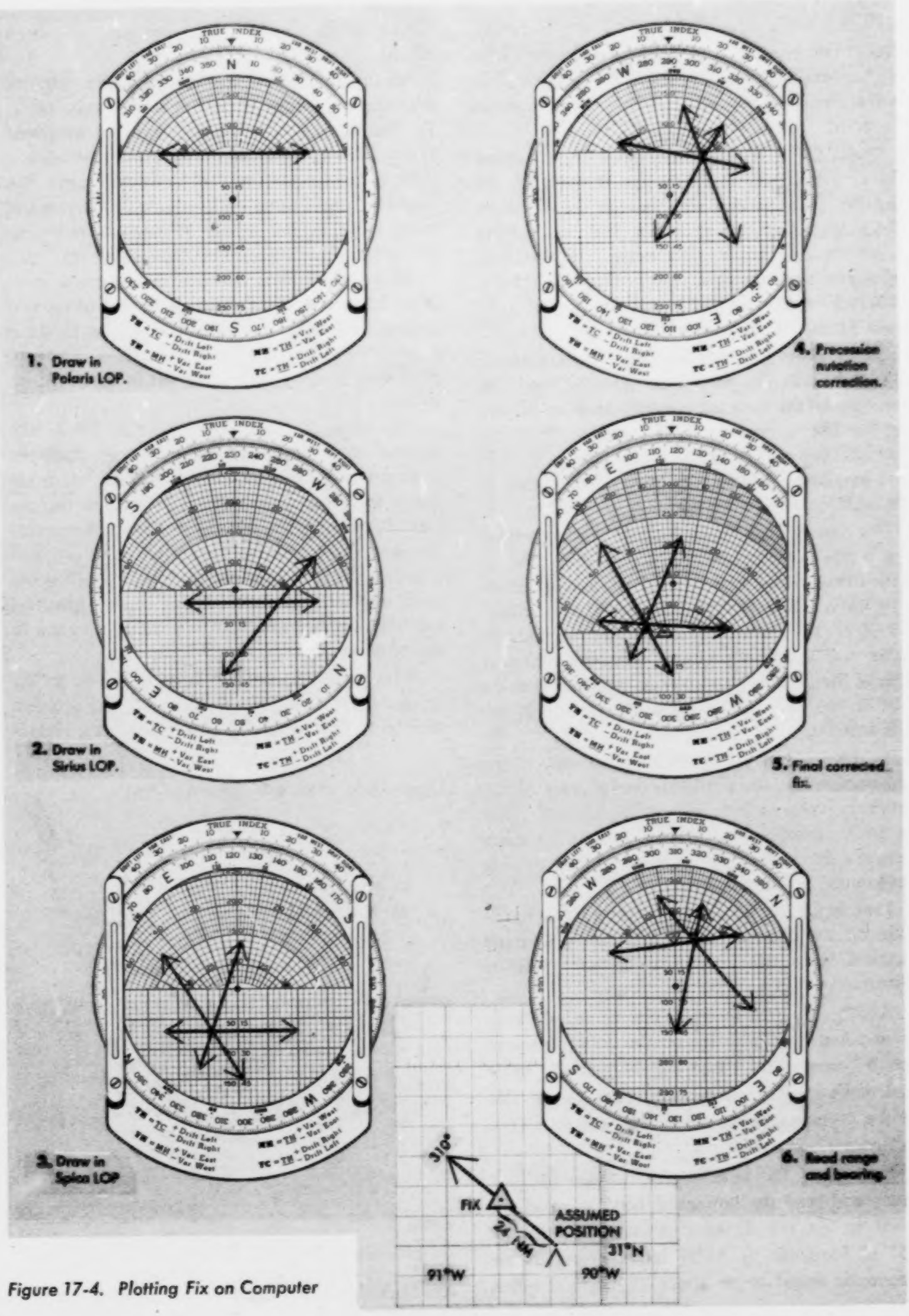

TRUE INDEX
1. Draw in Polaris LOP.
2. Draw in Sirius LOP.
3. Draw in Spica LOP
4. Precession nutation correction.
5. Final corrected fix.
6. Read range and bearing.
TH = TC + Drift Left − Drift Right
TH = MH + Var East − Var West
MH = TH + Var West − Var East
TC = TH + Drift Right − Drift Left
310°
FIX
24 NM
ASSUMED POSITION
31°N
91°W
90°W

Figure 17-4. Plotting Fix on Computer

position obtained in step 4. (If the Coriolis/rhumb line correction had been a correction left, the box would have been moved to the left.) This is the final corrected fix. Place a triangle about the point.

6. Place the final fix (inside the triangle) above the grommet with the zero line through the fix and the center vertical also through the fix. Read the range under the grommet and the bearing under the true index. The range is 24 nautical miles and the bearing is 310°. Hence the fix is plotted 24 nautical miles in the direction of 310° from 31°N, 90°18′W as shown.

When more than one assumed position exists, a slightly different procedure must be used. In this case all the assumed positions must be plotted on the DR computer before starting. Since the grommet can only be assigned one value of latitude and longitude, it is usually assigned the value of the middle assumed position.

For example, all three assumed positions have the same latitude 36°00′N but the first is 119°14′W, the second 119°29′W, and the third 119°44′W. The grommet is assigned the value 36°00′N 119°29′W. This is done so that the other two assumed positions will plot on either side of the grommet and no one assumed position will be too close to the edge of the face of the DR computer.

In this instance the first shot is 15′ *east* of the grommet value; the third shot is 15′ *west* of the grommet value, which is *not* 15 nautical miles at 36°N latitude. The distance in nautical miles between these assumed positions can be quickly determined in several ways.

- Probably the easiest way is to take 15′ of longitude off the chart at 36°N and see how many nautical miles this is on the latitude scale as illustrated in figure 17-5.
- Another quick way to determine the distance is to solve it graphically on the square grid of the DR computer. Place 0° (N), at the index and make a point 15 nautical miles to the side of the grommet, using the square grid as shown in figure 17-6A.

Next place the latitude, 36°, under the true index and read the horizontal component of the point to get the distance in nautical miles of 15′ of longitude at 36°N latitude. Again the answer is found to be about 12 nautical miles. Notice in figure 17-6B that the slide has been moved.

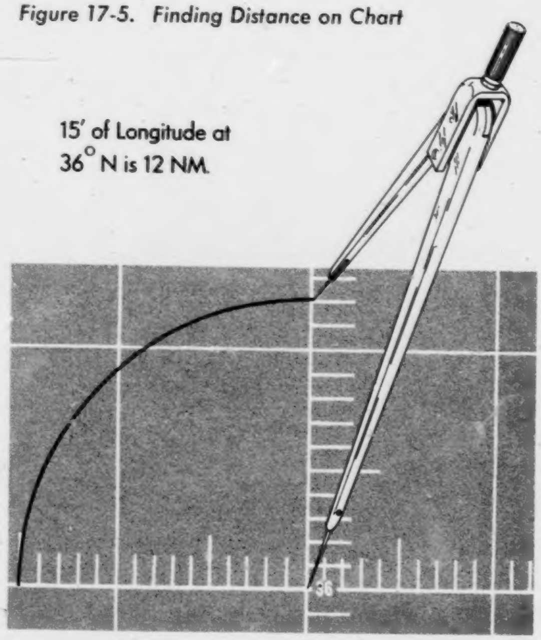
- An additional fast way to solve the distance is to use the motion of the body correction table. To find the length of one degree of longitude at any latitude, enter this table under the latitude using a true azimuth of 090°. At 36° north, the length of one degree of longitude is 49 nautical miles. One degree equals 49 nautical miles, so 15′ of longitude equals 12½ nautical miles.

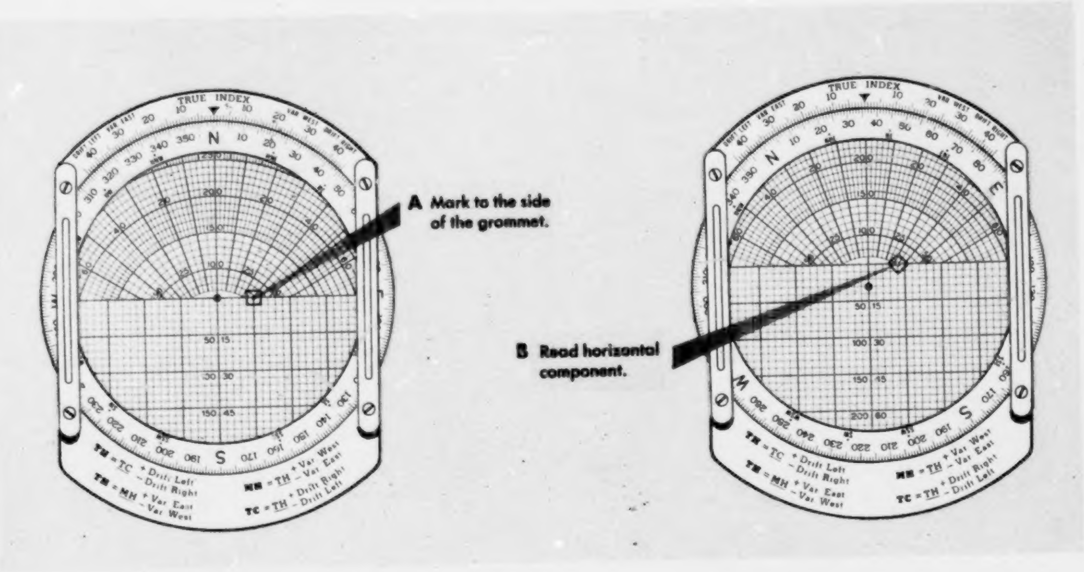
After the distance between the assumed positions has been determined, plot the other two assumed positions, circle them, and label all three as to first, second, or third shot. This is always done with 0° (N) under the true index as shown in figure 17-7.

Then plot the first LOP above or below the *number one* assumed position rather than the grommet. The second LOP is plotted above or below the grommet which is the number two assumed position. The third LOP is plotted intercept distance below or above the number three assumed position. The uncorrected fix is corrected in the usual manner, and the range and bearing obtained are from 36°N 119°29′W, the value assigned to the grommet.

If the intercepts are too large to handle in the regular manner on the DR computer, the problem may be solved by halving all the distances, includ-

Figure 17-5. Finding Distance on Chart




TRUE INDEX
DRIFT LEFT VAR EAST
VAR WEST DRIFT RIGHT
N
S
E
W
TH = TC + Drift Left − Drift Right
TH = MH + Var East − Var West
MH = TH + Var West − Var East
TC = TH + Drift Right − Drift Left

A Mark to the side of the grommet.

B Read horizontal component.

Figure 17-6. Finding Distance on Computer

ing the distance between the assumed positions as well as the intercept distances. All bearings remain unchanged. Do not forget to also halve the precession/nutation and Coriolis/rhumb line corrections. The final distance to the fix as read on the DR computer is doubled to give the range. The bearing is still read under the true index.

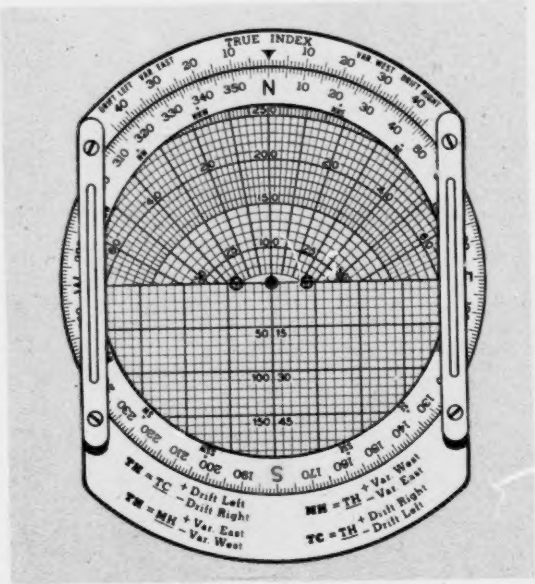

TRUE INDEX
DRIFT LEFT VAR EAST
VAR WEST DRIFT RIGHT
N
S
TH = TC + Drift Left − Drift Right
TH = MH + Var East − Var West
MH = TH + Var West − Var East
TC = TH + Drift Right − Drift Left

Figure 17-7. Plot Assumed Positions

SUMMARY

Celestial precomputation methods have been brought to the forefront with the advent of high-speed aircraft. The speeds at which aircraft now fly make it necessary to reduce the time between the last observation and the final fix.

The periscopic sextant may be the only means of viewing the sky. In this case, it is necessary to precompute the altitude and azimuth of a body in order to locate it.

There are two basic methods of precomputation, each with many variations. The mathematical solution, with assists from various types of computers, is favored over the graphical solution.

One of the main points to remember when precomputing is that corrections may be applied to either the Hc, Hs, or intercept. Pay particular attention to the sign of the correction. In addition to precomputation, the speed with which a fix is obtained may be increased by using special plotting techniques. The true azimuths may be preplotted, or the fix may be plotted on the DR computer.

CHAPTER 18

Star Identification

You can locate the navigational stars in the heavens by the use of constellations, by pointer systems, or by the geometric patterns they form. You can also locate celestial bodies by computing their altitudes and azimuths and inserting this information into a periscopic sextant. Therefore, a knowledge of their appearance within the field of view of the periscopic sextant is important.

STAR CHART AND LOCATION DIAGRAMS

Since the many stars and planets look very much alike, their identity is not as readily apparent as that of the sun or moon. To aid the navigator, the *Air Almanac* contains:

- A Navigational Star Chart.
- Sky Diagrams.
- A Planet Location Diagram.

Navigational Star Chart

The Navigational Star Chart shows stars in their correct positions according to their declination and SHA. The stars of each constellation are connected by dotted lines, and the names of the constellations are given.

Sky Diagrams

The Sky Diagrams are useful in selecting the most suitable stars and planets for navigation. Shown on the diagrams are the 57 selected navigational stars, the sun, the moon, the four planets (Venus, Mars, Jupiter, and Saturn), and the north and south celestial poles. For each month there is a series of diagrams depicting the sky for different latitudes at two-hour intervals throughout the day.

Planet Location Diagram

The Planet Location Diagram shows the daily relative positions of the sun, the moon, the planets (Mercury, Venus, Mars, Jupiter, Saturn), and the stars Aldebaran, Antares, Spica, and Regulus. The first point of Aries is also shown. This diagram should be used in conjunction with the Sky Diagrams.

SEASONAL STAR CHARTS

The seasonal star charts shown in figures 18-1 through 18-4 assist the navigator in star identification. The major constellations and other stars visible during each season are shown on each chart. If the chart for the current season is held overhead, with the top of the chart oriented to the north, the chart will indicate the positions of the stars.

The names of the stars and constellations appear relative to the bodies to which they apply. The broken lines connect stars of some of the more prominent constellations. The solid lines point out certain useful relationships and indicate the celestial equator. The celestial poles are marked by crosses.

The charts are designed so the center of the chart coincides with the observer's celestial meridian at midnight of midseason. Each chart extends 20° beyond both poles and four hours (60°) either side of the meridian at the equator. This coverage does not, of course, coincide with the visible sky which is always a hemisphere.

The bodies on the celestial meridian above the zenith are north of the observer; those below are south. The observer's zenith is a function of

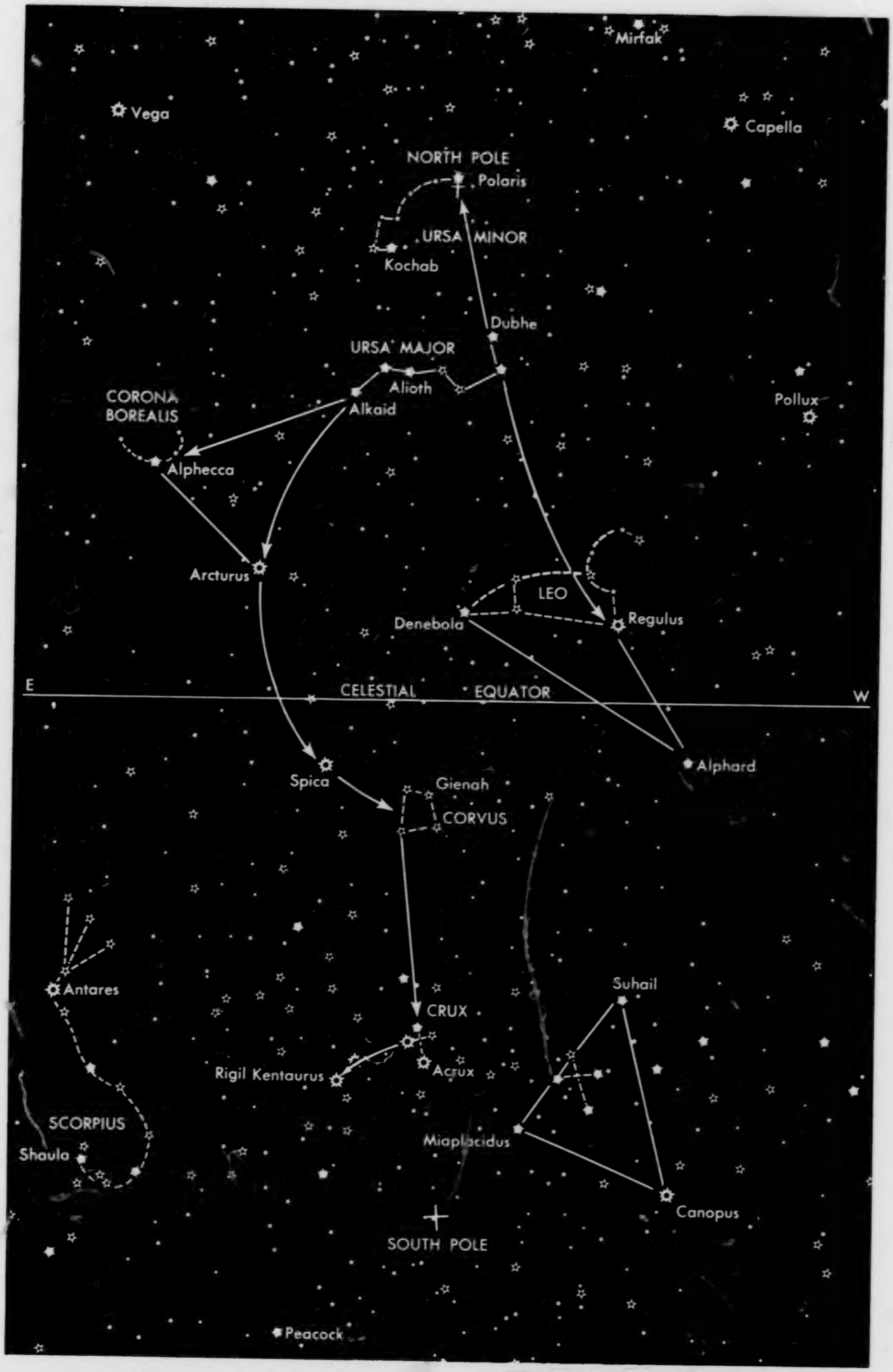

Mirfak
Vega
Capella
NORTH POLE
Polaris
URSA MINOR
Kochab
Dubhe
URSA MAJOR
Alioth
CORONA BOREALIS
Alkaid
Pollux
Alphecca
Arcturus
LEO
Denebola
Regulus
E
CELESTIAL EQUATOR
W
Alphard
Spica
Gienah
CORVUS
Antares
Suhail
CRUX
Rigil Kentaurus
Acrux
SCORPIUS
Shaula
Miaplacidus
Canopus
SOUTH POLE
Peacock

Figure 18-1. Spring Stars

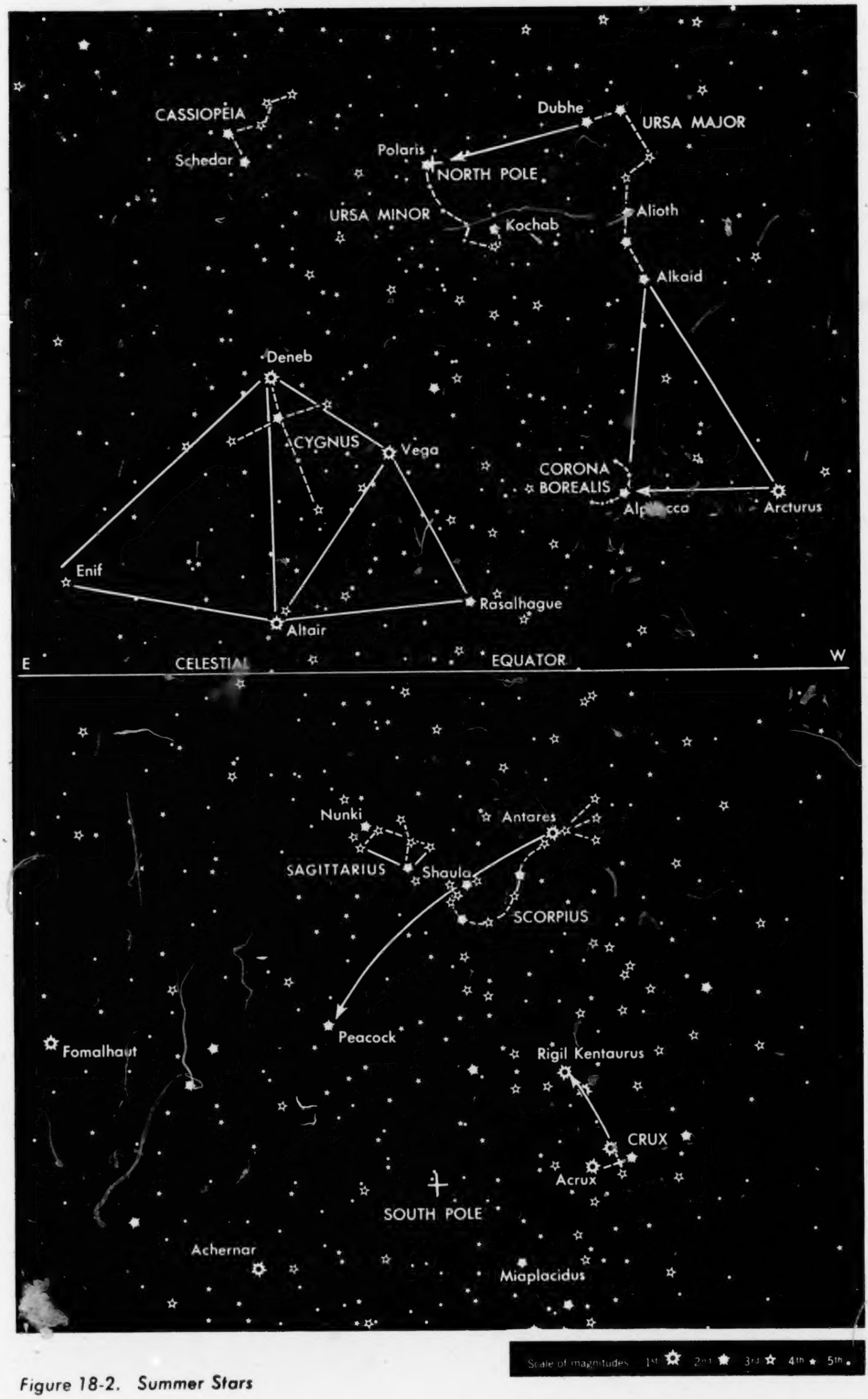

CASSIOPEIA
Schedar
Dubhe
URSA MAJOR
Polaris
NORTH POLE
URSA MINOR
Kochab
Alioth
Alkaid
Deneb
CYGNUS
Vega
CORONA BOREALIS
Alphecca
Arcturus
Enif
Rasalhague
Altair
E
CELESTIAL
EQUATOR
W
Nunki
Antares
SAGITTARIUS
Shaula
SCORPIUS
Peacock
Fomalhaut
Rigil Kentaurus
CRUX
Acrux
SOUTH POLE
Achernar
Miaplacidus
Scale of magnitudes 1st 2nd 3rd 4th 5th

Figure 18-2. Summer Stars

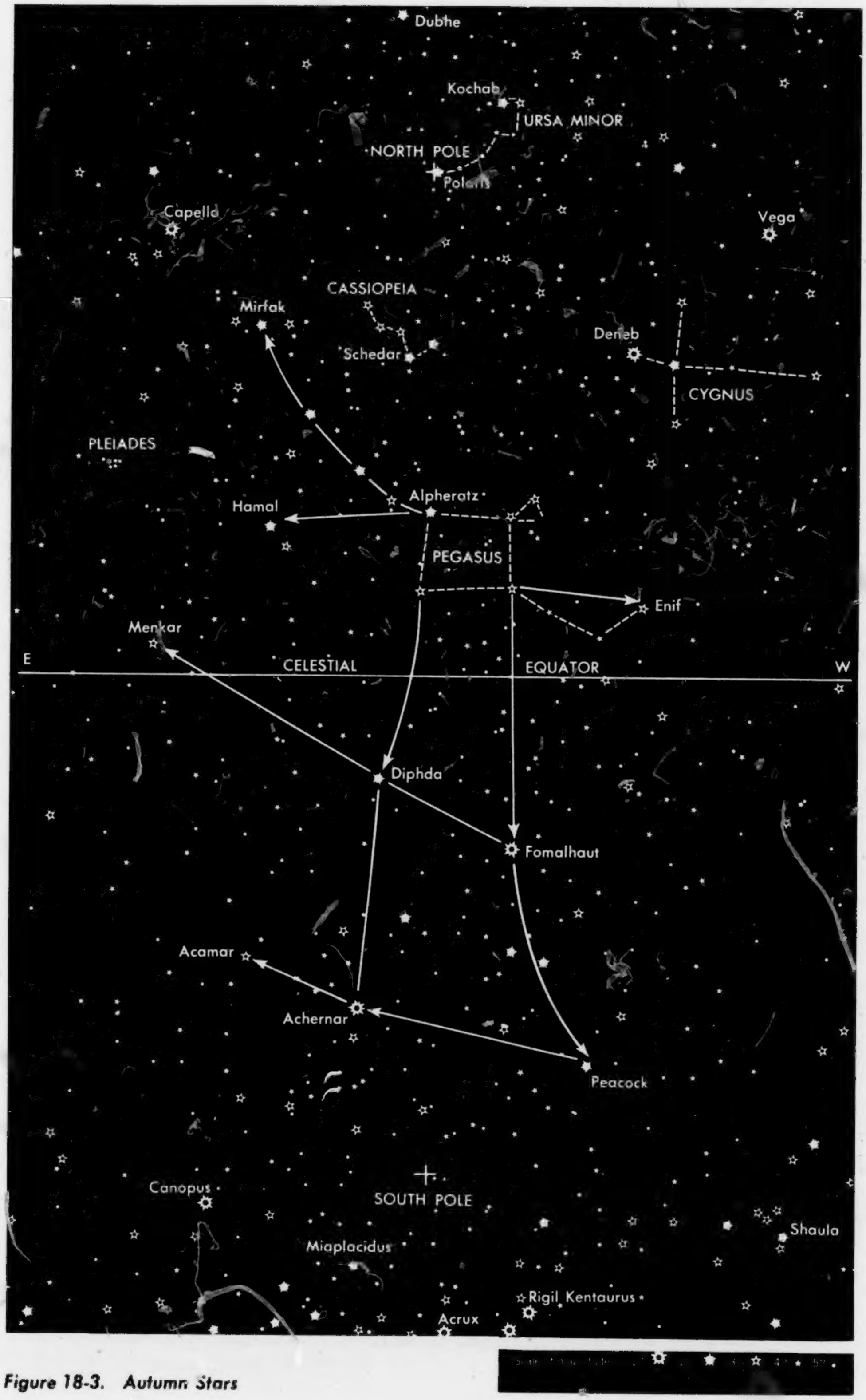

Dubhe
Kochab
URSA MINOR
NORTH POLE
Polaris
Capella
Vega
CASSIOPEIA
Mirfak
Schedar
Deneb
CYGNUS
PLEIADES
Alpheratz
Hamal
PEGASUS
Enif
Menkar
E
CELESTIAL
EQUATOR
W
Diphda
Fomalhaut
Acamar
Achernar
Peacock
Canopus
SOUTH POLE
Shaula
Miaplacidus
Rigil Kentaurus
Acrux

Figure 18-3. Autumn Stars

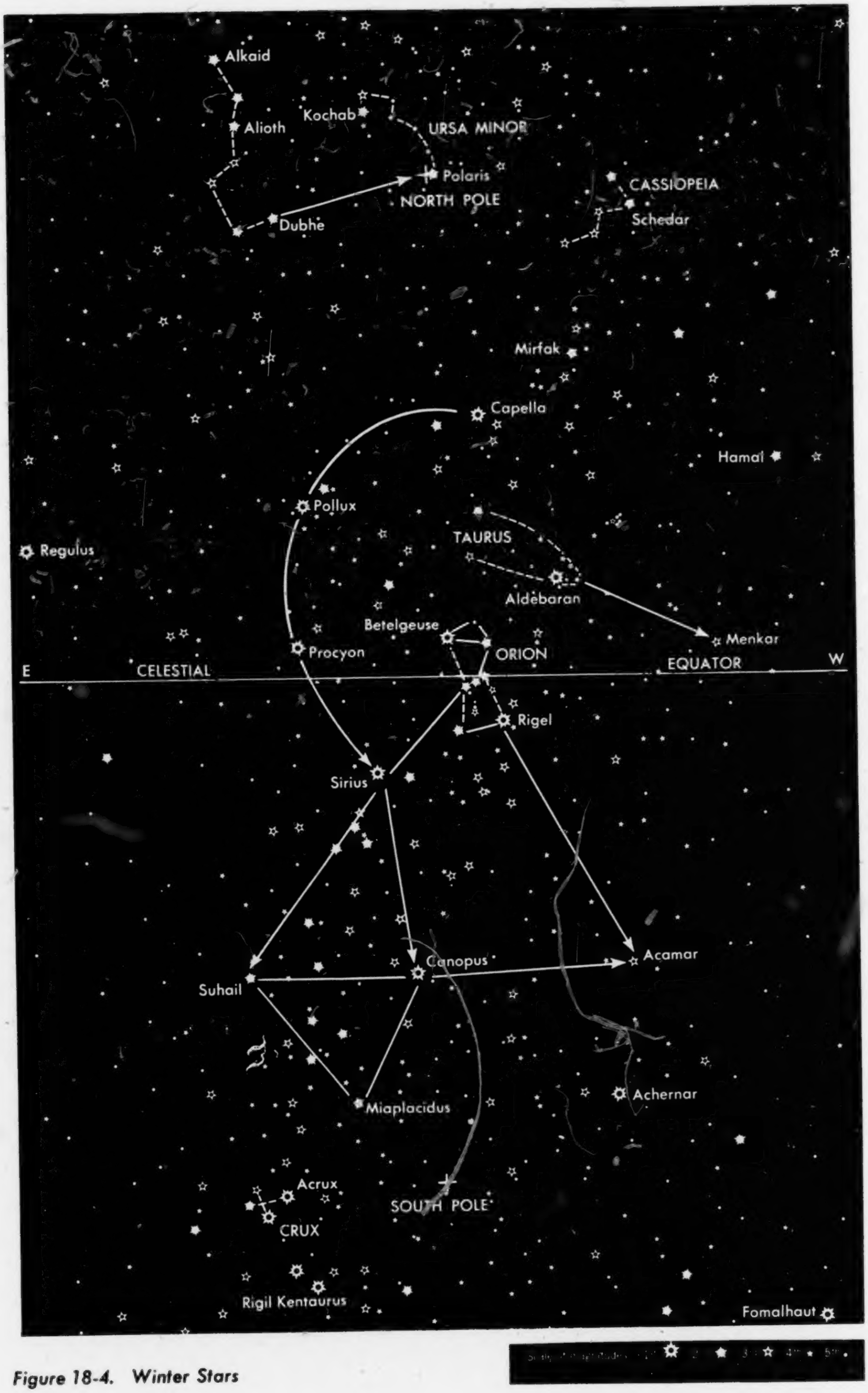

Alkaid
Alioth
Kochab
URSA MINOR
Polaris
NORTH POLE
Dubhe
CASSIOPEIA
Schedar
Mirfak
Capella
Hamal
Pollux
Regulus
TAURUS
Aldebaran
Betelgeuse
Menkar
Procyon
ORION
E
CELESTIAL
EQUATOR
W
Rigel
Sirius
Canopus
Acamar
Suhail
Achernar
Miaplacidus
Acrux
SOUTH POLE
CRUX
Rigil Kentaurus
Fomalhaut
Scale of magnitudes 1st
2
3
4th
5th

Figure 18-4. Winter Stars

Acamar	C-1	Antares	D-2	Fomalhaut	D-1	Procyon	B-2
Achernar	C-1	Arcturus	A-2	Gienah	D-2	Rasalhague	A-2
Acrux	D-2	Betelgeuse	B-1	Hamal	B-1	Regulus	B-2
Aldebaran	B-1	Canopus	C-2	Kochab	A-2	Rigel	C-1
Alioth	A-2	Capella	B-1	Menkar	B-1	Rigil Kent	D-2
Alkaid	A-2	Deneb	A-1	Miaplacidus	C-2	Schedar	B-1
Alphard	C-2	Denebola	B-2	Mirfak	B-1	Shaula	D-2
Alphecca	A-2	Diphda	C-1	Nunki	D-1	Sirius	C-2
Alpheratz	B-1	Dubhe	B-2	Peacock	D-1	Spica	D-2
Altair	A-1	Enif	A-1	Pollux	B-2	Suhail	C-2
						Vega	A-1

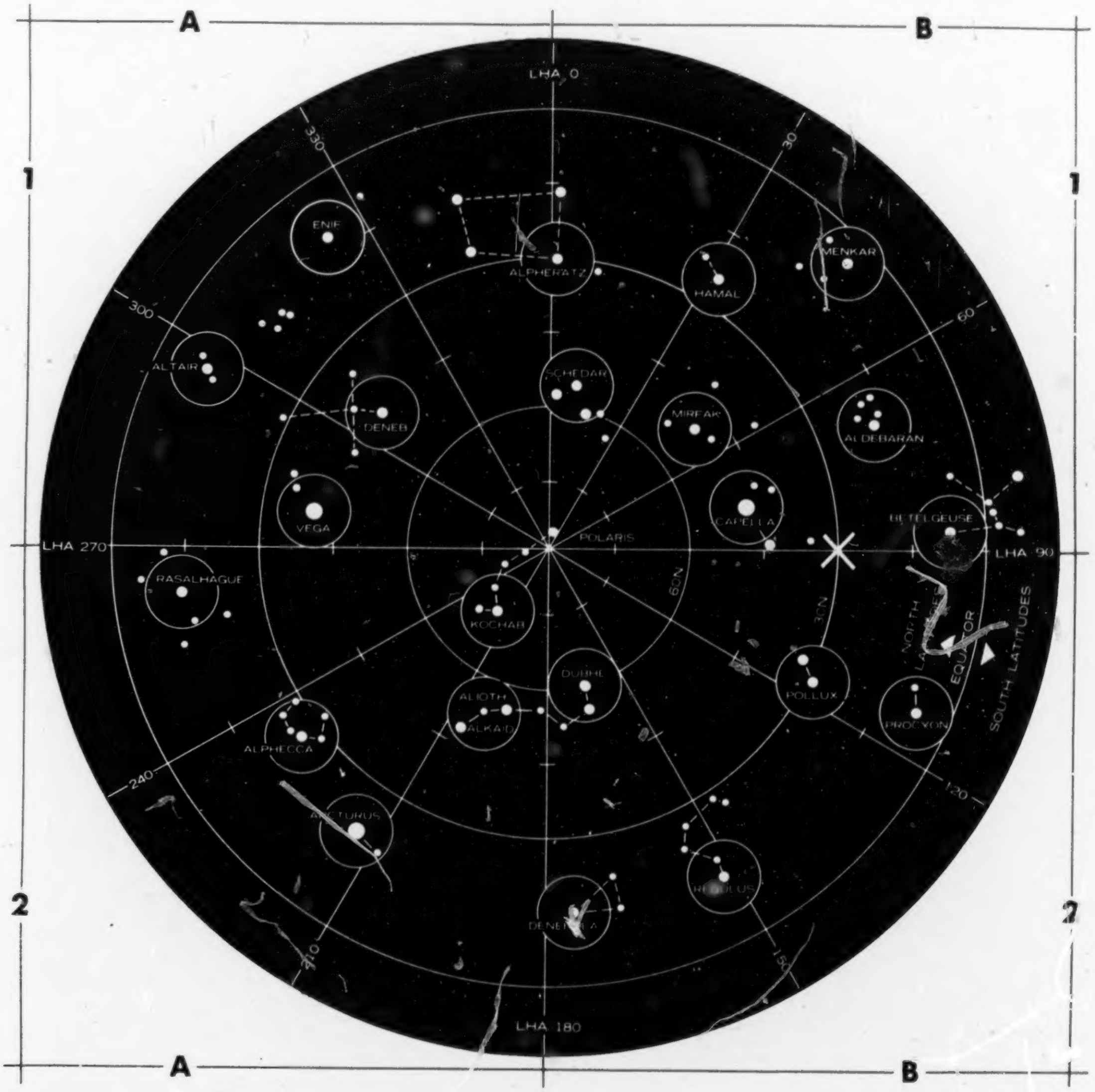

A
B
1
1
LHA 0
330
30
ENIF
ALPHERATZ
MENKAR
HAMAL
300
60
ALTAIR
SCHEDAR
DENEB
MIRFAK
ALDEBARAN
VEGA
CAPELLA
BETELGEUSE
LHA 270
POLARIS
LHA 90
RASALHAGUE
60N
KOCHAB
30N
NORTH LATITUDES
EQUATOR
SOUTH LATITUDES
DUBHE
POLLUX
PROCYON
ALIOTH
ALKAID
ALPHECCA
240
120
ARCTURUS
REGULUS
DENEBOLA
210
150
LHA 180
2
2
A
B

Figure 18-5. North Polar Sextant Star Identification Diagram

Acamar	C-1	Antares	D-2	Fomalhaut	D-1	Procyon	B-2
Achernar	C-1	Arcturus	A-2	Gienah	D-2	Rasalhague	A-2
Acrux	D-2	Betelgeuse	B-1	Hamal	B-1	Regulus	B-2
Aldebaran	B-1	Canopus	C-2	Kochab	A-2	Rigel	C-1
Alioth	A-2	Capella	B-1	Menkar	B-1	Rigil Kent	D-2
Alkaid	A-2	Deneb	A-1	Miaplacidus	C-2	Schedar	B-1
Alphard	C-2	Denebola	B-2	Mirfak	B-1	Shaula	D-2
Alphecca	A-2	Diphda	C-1	Nunki	D-1	Sirius	C-2
Alpheratz	B-1	Dubhe	B-2	Peacock	D-1	Spica	D-2
Altair	A-1	Enif	A-1	Pollux	B-2	Suhail	C-2
						Vega	A-1

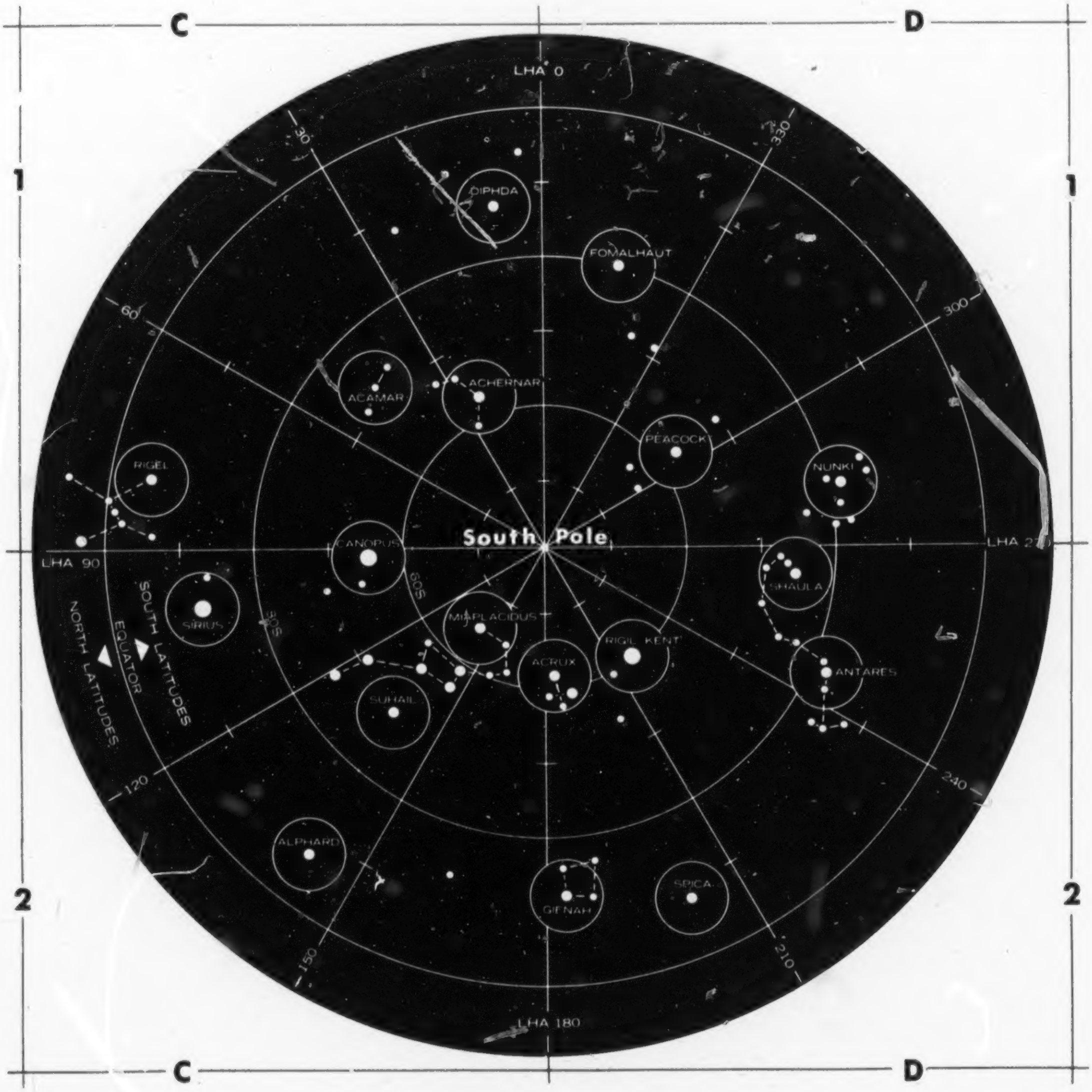

C
D
1
1
2
2
LHA 0
30
330
60
300
LHA 90
LHA 270
120
240
150
210
LHA 180
DIPHDA
FOMALHAUT
ACAMAR
ACHERNAR
PEACOCK
RIGEL
NUNKI
CANOPUS
South Pole
SHAULA
SIRIUS
60S
30S
MIAPLACIDUS
RIGIL KENT
ACRUX
ANTARES
SUHAIL
ALPHARD
GIENAH
SPICA
SOUTH LATITUDES
EQUATOR
NORTH LATITUDES
C
D

Figure 18-6. South Polar Sextant Star Identification Diagram

latitude. If the observer's latitude is 30° N, his zenith is 30/90, or 1/3 the distance from the equator to the north pole.

The center of the chart will coincide with the observer's celestial meridian at the following local mean times:

LMT	Spring Stars	Summer Stars	Autumn Stars	Winter Stars
1800	22 Jun	21 Sep	21 Dec	22 Mar
2000	22 May	21 Aug	21 Nov	20 Feb
2200	22 Apr	22 Jul	21 Oct	20 Jan
0000	23 Mar	22 Jun	22 Sep	22 Dec
0200	21 Feb	23 May	22 Aug	22 Nov
0400	21 Jan	22 Apr	23 Jul	22 Oct
0600	22 Dec	23 Mar	22 Jun	21 Sep

SEXTANT STAR DIAGRAMS

With the periscopic sextant, the traditional methods of star location cannot be used because of the sextant's limited field of view. To aid in locating stars with a periscopic sextant, the Sextant Star Identification Diagrams have been devised. These are shown in figure 18-5 and 18-6. They are used as follows.

1. Locate the star on the diagram by referring to the star location guide in figure 18-5. The margin of the diagrams have letters and numbers to aid in finding the stars on the diagram.
2. Locate the point of intersection of computed LHA ♈ and the observer's latitude in the diagrams. Hold the diagram so the top of the field of view is the point on the circle nearest the intersection point.

Example:

Menkar	(Co-ordinates B-1)
LHA ♈	= 090°
Lat	= 30°N

The result is shown in figure 18-7.

SUMMARY

Even with the technique of presetting the periscopic sextant, it is essential that the navigator be able to visually pick out the desired star from its background among other celestial bodies. To aid the navigator in learning star identification several references are available. These are the *Air Almanac,* seasonal star charts and sextant star diagrams.

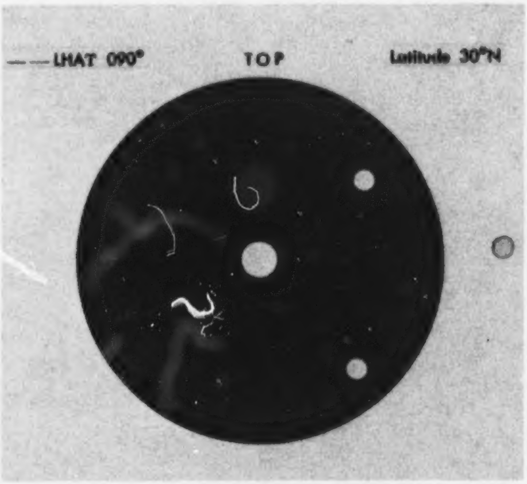


Figure 18-7. Periscopic Sextant Field of View of Menkar

CHAPTER 19

Grid Navigation

The original purpose of grid navigation was to ease the difficulties facing the navigator during high latitude flights. Grid navigation has since been found helpful at all latitudes. This is particularly true on long routes because a great circle course is flown whenever grid is used for a heading reference. Grid is simply a reorientation of the heading reference; it does not alter standard fixing techniques.

PROBLEMS ENCOUNTERED IN POLAR NAVIGATION

Two factors peculiar to polar areas which make steering more difficult than usual are (1) the magnetic compass becomes highly unreliable, and (2) geographic meridians converge at acute angles. The combined effect of these two factors rules out steering by conventional methods. Each factor is examined below.

Unreliability of Magnetic Compass

Maintaining an accurate heading in high latitudes is difficult when a magnetic compass is used as the heading indicator. Built to align itself with the *horizontal* component of the earth's magnetic field, the compass instead must react to the strong *vertical* component which predominates near the magnetic poles. Here the horizontal component is too weak to provide a reliable indication of direction. As a result, compass performance becomes sluggish and inaccurate. The situation is further aggravated by the frequent magnetic storms in the polar regions which shift the magnetic lines of force.

But even if these conditions did not exist, the mere proximity of the magnetic poles would sharply reduce compass usefulness. While the aircraft flew a straight course, the compass indicator would swing rapidly, faithfully pointing at a magnetic pole passing off to the left or right.

A similar difficulty arises from the manner in which geographic meridians sharply converge at the true poles.

Problem of Converging Meridians

The nature of the conventional geographic coordinate system is such that all meridians converge at the poles. Each meridian represents a degree of longitude, each is aligned with true north and true south. On polar charts, the navigator encounters one degree of change in his true course for each meridian he crosses, and the more closely he approaches a pole, the more rapidly he crosses meridians. Thus, even in straight-and-level flight along a great circle course, true course can change several degrees over a short period of time. The navigator finds himself in the extremely peculiar position of having to place the aircraft in a constant turn in order to maintain a straight course. For precision navigation, such a procedure is clearly out of the question. Notice in figure 19-1 that the course changes 60° between *A* and *B*, and, much nearer the pole, between *C* and *D*, it changes 120°.

GRID CHART PROJECTIONS

The three polar projections most commonly used in polar areas for grid navigation are the transverse Mercator, the polar stereographic, and the polar gnomonic. The transverse Mercator and polar stereographic projections are used in flight; the polar gnomonic is used only for planning. The

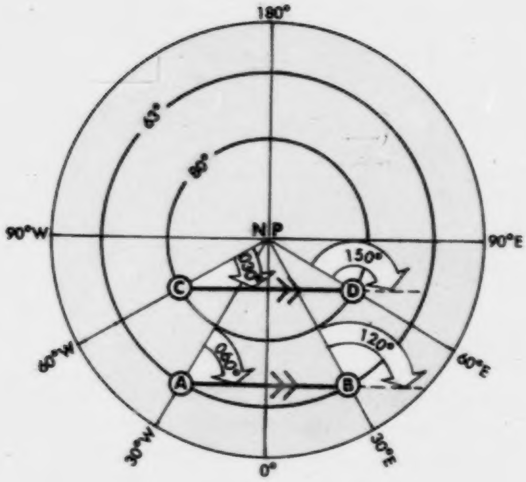

180°
65°
80°
NP
90°W
90°E
150°
C
D
120°
A
B
60°W
60°E
30°W
30°E
0°

Figure 19-1. Converging Meridians

Lambert conformal projection is the one most commonly used for grid flight in subpolar areas. The division between polar and subpolar projections varies among the aeronautical chart series. For example, the division is at 70° of latitude for the JN series, at 80° of latitude for the ONC and PC series, and at 84° of latitude for the 1510 AIR series.

USAF GRID OVERLAY

The graticule of the USAF grid overlay eliminates the problem of converging meridians (see figure 19-2). It is a square grid, and though its meridians are aligned with grid north (GN), they do not converge at grid north.

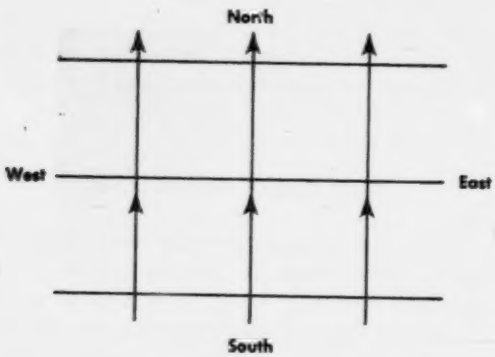

North
West
East
South

Figure 19-2. USAF Grid Overlay

While the USAF grid overlay can be superimposed on any projection, it is most commonly used with the polar stereographic (for flights in polar areas) and the Lambert conformal (for flights in subpolar areas). This is because a straight line on these projections approximates a great circle. In figures 19-3 and 19-4, you can see that, as the great circle course crosses the true meridians, its *true* direction changes but its *grid* direction remains constant.

All grid meridians are parallel to the Greenwich meridian, and true north along the Greenwich meridian is the direction of grid north over the entire chart as shown in figure 19-5.

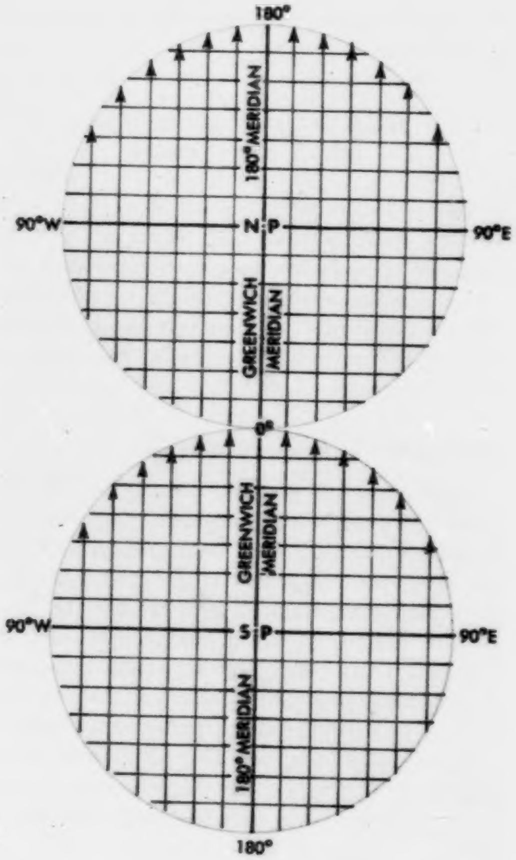

180°
180° MERIDIAN
90°W
N P
90°E
GREENWICH MERIDIAN
0°
GREENWICH MERIDIAN
90°W
S P
90°E
180° MERIDIAN
180°

Figure 19-5. Orientation of Grid North

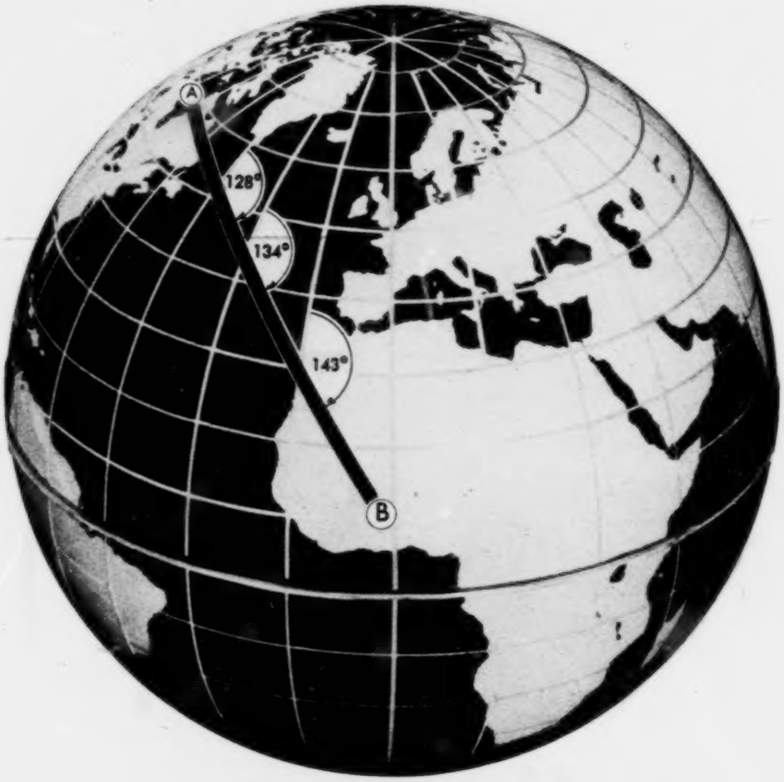

A
128°
134°
143°
B

Figure 19-3. True Direction of Great Circle Course Changes

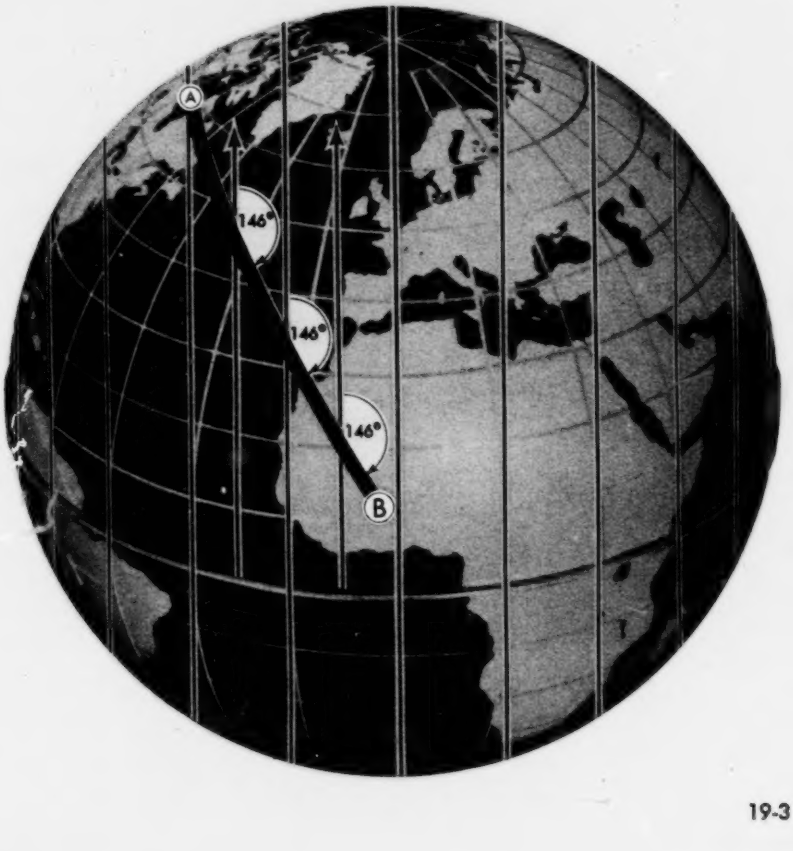

A
146°
146°
146°
B

Figure 19-4. Grid Direction of Great Circle Course is Constant

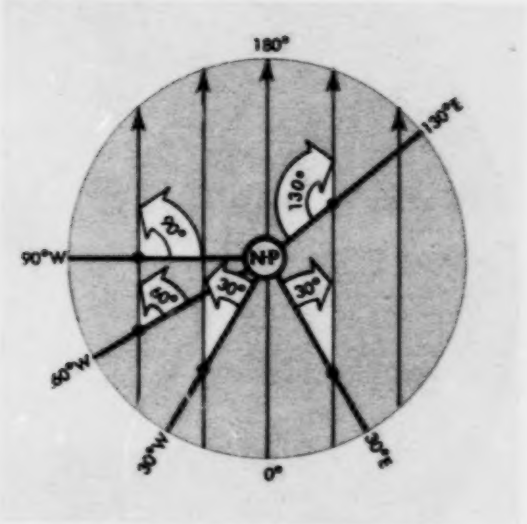

180°
130°E
130°
90°W
90°
N.P
60°
30°
30°
60°W
30°W
0°
30°E

Figure 19-6. Grid North/True North Relationship on Typical Polar Projection

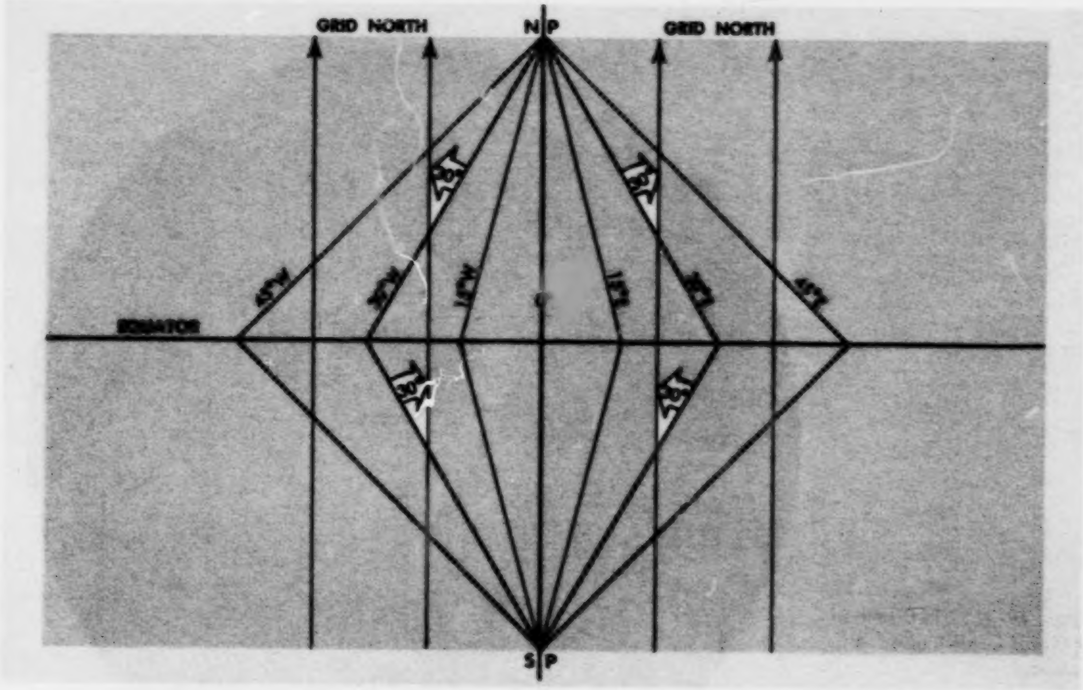

GRID NORTH
N P
GRID NORTH
45°W
30°W
15°W
0
15°E
30°E
45°E
EQUATOR
S P

Figure 19-7. Grid North/True North Relationship in All Quadrants of the Sphere

Relationship of Grid North to True North

Because grid meridians are parallel to the Greenwich meridian, the angle between grid north and true north is governed by the navigator's longitude and the convergence factor of his chart.

CONVERGENCE FACTORS OF 1.0. Figure 19-6 shows that charts having convergence factors of 1.0 display the grid north (GN) to true north (TN) relationship as a direct function of longitude. In the northern hemisphere at 30° W, grid north is 30° west of true north; at 60° W, GN is 60° west of TN. Similarly, at 130° E longitude, GN is 130° east of TN.

In the southern hemisphere, the direction of GN with respect to TN is exactly opposite.

Figure 19-7 illustrates the geometric relationship between grid north and the convergence of true meridians.

CONVERGENCE FACTORS OF LESS THAN 1.0. Figure 19-8 shows a chart with a convergence factor of less than 1.00, with a USAF grid overlay superimposed on it. The relationship between GN and TN on this chart is determined in the same manner as on charts with a convergence factor of 1.0. On charts with a convergence factor of less than 1.0, the value of the convergence angle at a given longitude is always smaller than the value of the longitude.

Relationship of Grid Direction to True Direction

The navigator uses the following formulas to determine grid direction.

IN THE NORTHERN HEMISPHERE:

Grid direction = true direction + west convergence angle.

Grid direction = true direction — east convergence angle.

IN THE SOUTHERN HEMISPHERE:

Grid direction = true direction — west convergence angle.

Grid direction = true direction + east convergence angle.

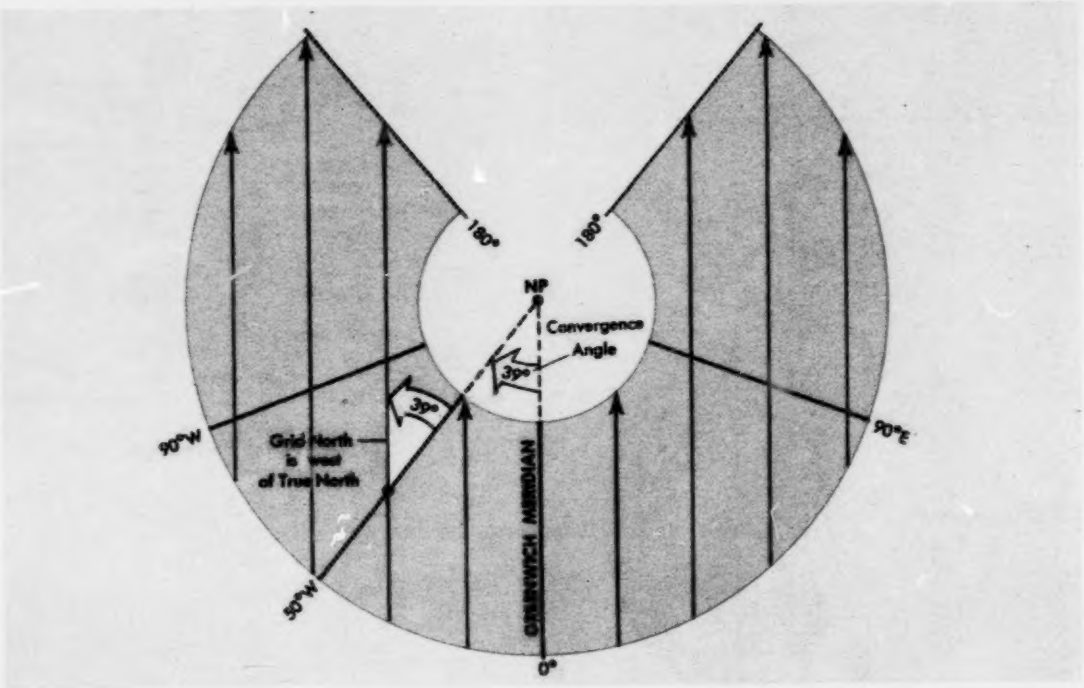


Figure 19-8. Grid Overlay Superimposed on Lambert Conformal (Convergence Factor 0.785)

Polar Angle

Polar angle can be used to relate true direction to grid direction. *Polar angle* is measured clockwise through 360° from GN to TN as illustrated in figure 19-9. It is simple to convert from one directional reference to the other by use of the formula:

Grid direction = true direction + polar angle. To determine polar angle from convergence angle, apply the following formulas illustrated in figure 19-10.

In the Northwest and Southeast Quadrants:

Polar angle = convergence angle.

In the Northeast and Southwest Quadrants:

Polar angle = 360° — convergence angle.

Chart Transition

Since the relation of the true meridians and the grid overlay on subpolar charts differs from that on polar charts, the overlays do not match when a transition is made from one chart to the other. Therefore, the grid course (GC) of a route on a subpolar chart will be different than the GC of the same route on a polar chart.

The chart transition problem is best solved during flight planning.

1. Select a transition point common to both charts.
2. Measure the subpolar GC and the polar GC.
3. Compute the difference between the GCs obtained in step 2. This is the amount the compass pointer must be changed at the transition point.
4. If the GC on the first chart is *smaller* than the

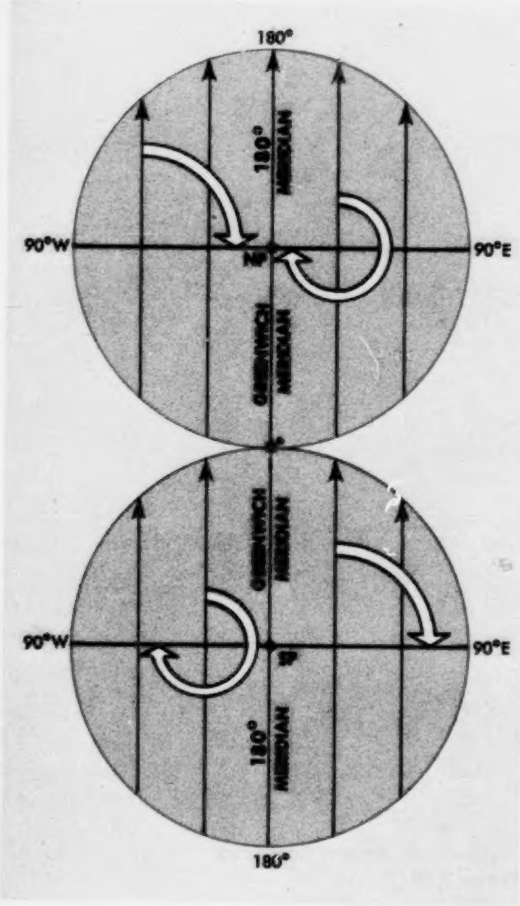

180°
180° MERIDIAN
90°W
90°E
NP
GREENWICH MERIDIAN
GREENWICH MERIDIAN
90°W
90°E
SP
180° MERIDIAN
180°

Figure 19-9. Polar Angle Measured Clockwise from Grid North to True North

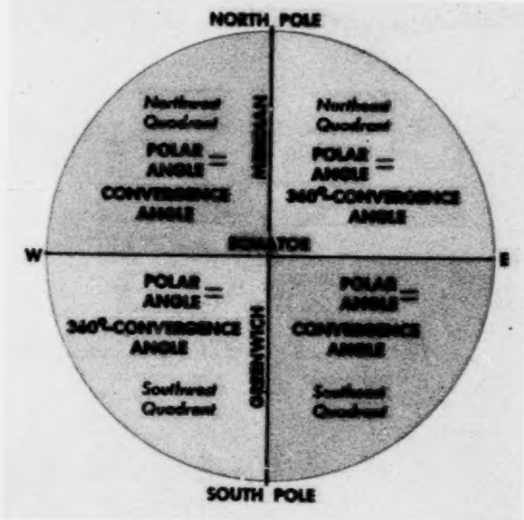

NORTH POLE
Northwest Quadrant
POLAR ANGLE = CONVERGENCE ANGLE
MERIDIAN
Northeast Quadrant
POLAR ANGLE = 360°-CONVERGENCE ANGLE
W
EQUATOR
E
POLAR ANGLE = 360°-CONVERGENCE ANGLE
GREENWICH
POLAR ANGLE = CONVERGENCE ANGLE
Southwest Quadrant
Southeast Quadrant
SOUTH POLE

Figure 19-10. Polar Angle

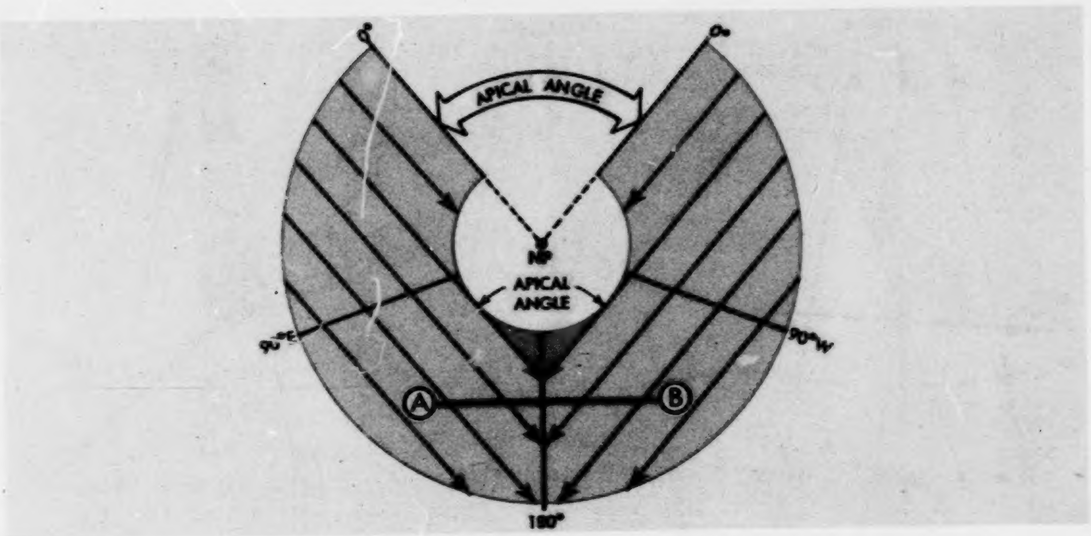


Figure 19-11. Crossing 180th Meridian on Subpolar Chart

GC on the second chart, *add* the GC difference to the compass pointer reading and reposition the compass pointer; if the GC on the first chart is *larger, subtract* the GC difference.

Rule: Smaller GC to larger GC; ADD
Larger GC to smaller GC; SUBTRACT

Example:

1. Chart transition from a subpolar to a polar chart.
2. GC on sub-polar chart is 316°.
   GC on polar chart is 308°.
   GC difference is 8°.
3. Compass pointer reading (grid heading) is 320°.
4. The transition is from a larger GC to a smaller GC; therefore, the GC difference (8°) is subtracted from the compass pointer reading (320°). The compass pointer is then repositioned to the new grid heading (312°).

CAUTION

Do not alter the aircraft's heading; instead, reposition the compass pointer to the new grid heading.

Crossing 180th Meridian on Subpolar Chart

When a flight crosses the 180th meridian on a subpolar grid chart, the grid heading changes because of the convergence of grid meridians along this true meridian. When a navigator using a subpolar chart crosses the 180th meridian *on an easterly heading* (*A* to *B* in figure 19-11), he must *subtract the apical angle* from the grid heading. He must *add the apical angle* to the grid heading when *on a westerly heading* (*B* to *A* in figure 19-11). The apical angle can be measured on the chart at the 180th meridian between the converging GN references. The angle also can be computed by use of the following formula:

Apical angle = 360° — (360° × convergence factor).

Example:

Given: Chart convergence factor = .785

Find: Apical angle

$$\begin{aligned}\text{Apical angle} &= 360° - (360° \times 0.785)\\ &= 360° - 283°\\ &= 77°\end{aligned}$$

CAUTION

Do not alter the aircraft's heading when crossing the 180th meridian; instead, simply reposition the directional gyro compass pointer to the new grid heading.

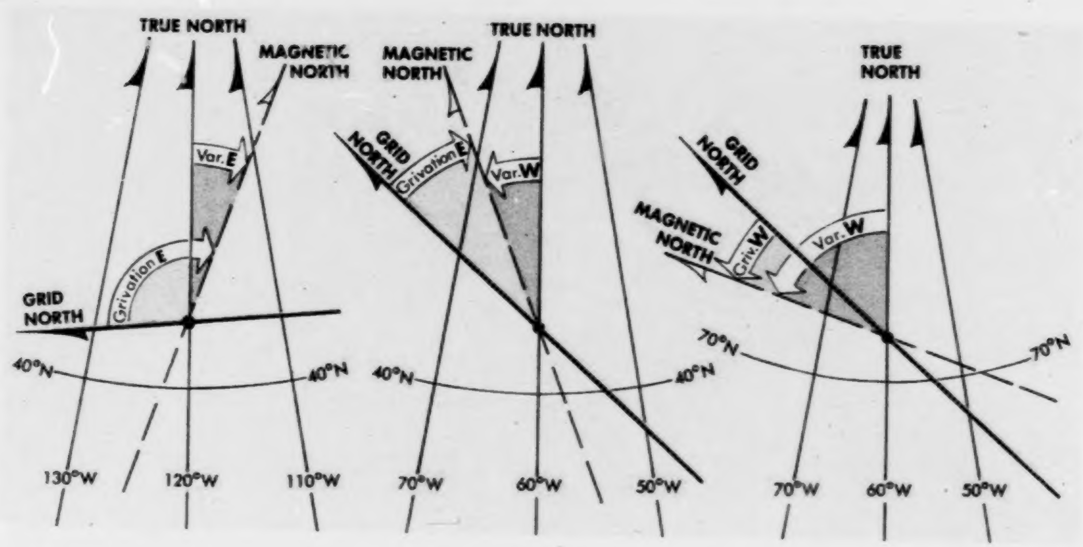

TRUE NORTH
MAGNETIC NORTH
Var. E
Grivation E
GRID NORTH
40°N
40°N
130°W
120°W
110°W
MAGNETIC NORTH
TRUE NORTH
GRID NORTH
Grivation E
Var. W
40°N
40°N
70°W
60°W
50°W
TRUE NORTH
GRID NORTH
MAGNETIC NORTH
Griv. W
Var. W
70°N
70°N
70°W
60°W
50°W

Figure 19-12. Grivation

Grivation

The difference between the directions of the magnetic lines of force and grid north is called grivation (GV). Grivation is similar to variation and is used to convert magnetic heading to grid heading and vice versa. Figure 19-12 shows the relationship between GN, TN, and MN. Lines of equal grivation (isogrivs) are plotted on grid charts.

The formula for computing grivation is:

$$\text{Grivation} = (-\text{W conv. angle}) + \left(\begin{matrix}+\text{W}\\-\text{E}\end{matrix}\ \text{variation}\right)$$

$$\text{Grivation} = (+\text{E conv. angle}) + \left(\begin{matrix}+\text{W}\\-\text{E}\end{matrix}\ \text{variation}\right)$$

In the southern hemisphere, reverse the signs of west and east convergence angles in the formula above. If grivation is positive, it is W grivation; if grivation is negative, it is E grivation.

To compute magnetic heading from grid heading use the formula:

$$\text{Magnetic heading} = \text{Grid heading} \ \substack{+\text{W}\\-\text{E}}\ \text{grivation}$$

GYRO PRECESSION

To eliminate the difficulties imposed by magnetic compass unreliability in polar areas, the navigator disregards the magnetic compass in favor of a free running gyro. Gyro steering is used because it is stable and independent of magnetic influence.

When used as a steering instrument, the gyro is restricted so its spin axis always remains horizontal to the surface of the earth and is free to turn only in this horizontal plane. Any movement of a gyro spin axis from its initial horizontal alignment is called *precession*. The types of precession are:

- Real precession.
- Apparent precession, which includes:
    - Earth rate precession.
    - Transport precession.
    - Grid transport precession.

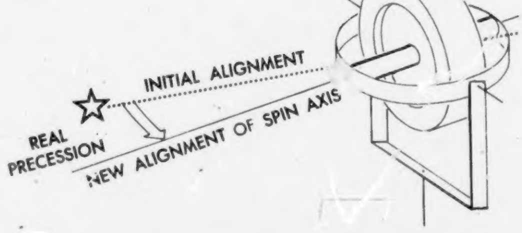
Total precession is the cumulative effect of real and apparent precession.

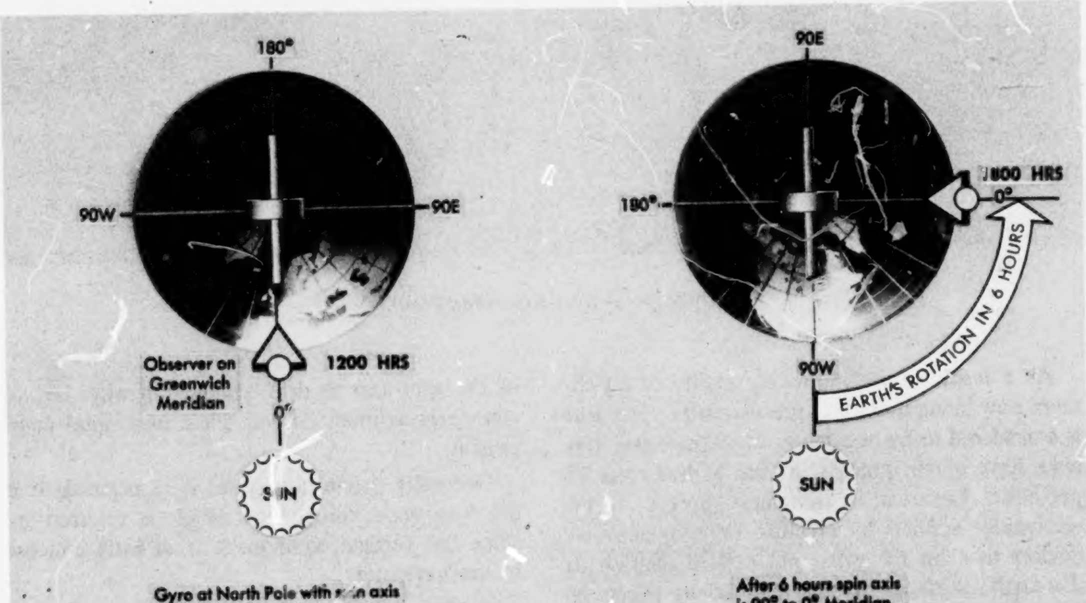
Real Precession

Real precession, illustrated in figure 19-13, is the actual movement of a gyro spin axis from its initial alignment in space. It is caused by such imperfections as:

Power fluctuation.
Imbalance of the gyro.
Friction in gyro gimble bearings.

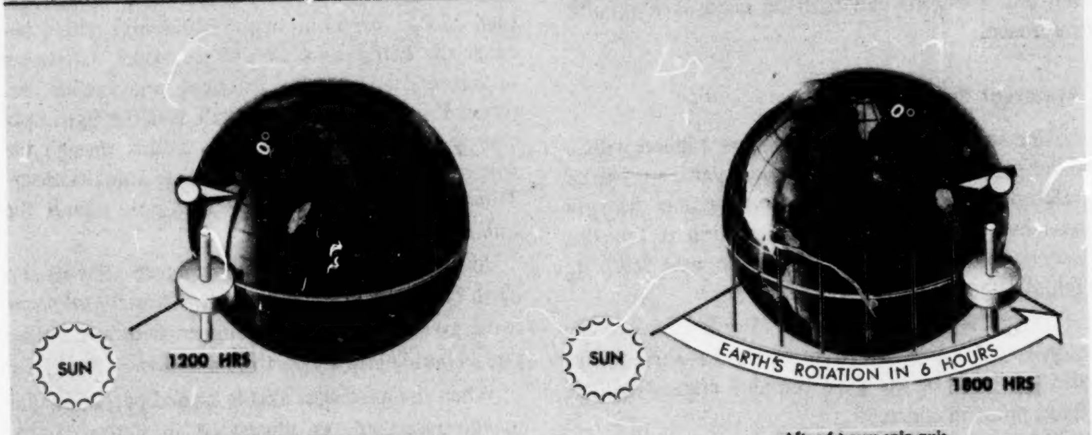
Figure 19-13. Real Precession


INITIAL ALIGNMENT
REAL PRECESSION
NEW ALIGNMENT OF SPIN AXIS


180°
90W
90E
Observer on Greenwich Meridian
1200 HRS
0°
SUN
90E
180°
1800 HRS
0°
90W
EARTH'S ROTATION IN 6 HOURS
SUN

Gyro at North Pole with spin axis parallel to 0° Meridian

After 6 hours spin axis is 90° to 0° Meridian.


SUN
1200 HRS
SUN
EARTH'S ROTATION IN 6 HOURS
1800 HRS

Gyro at Equator with spin axis parallel with 0° Meridian.

After 6 hours spin axis is still parallel with 0° Meridian.

Figure 19-14. Initial Location of Gyro Affects Earth Rate Precession

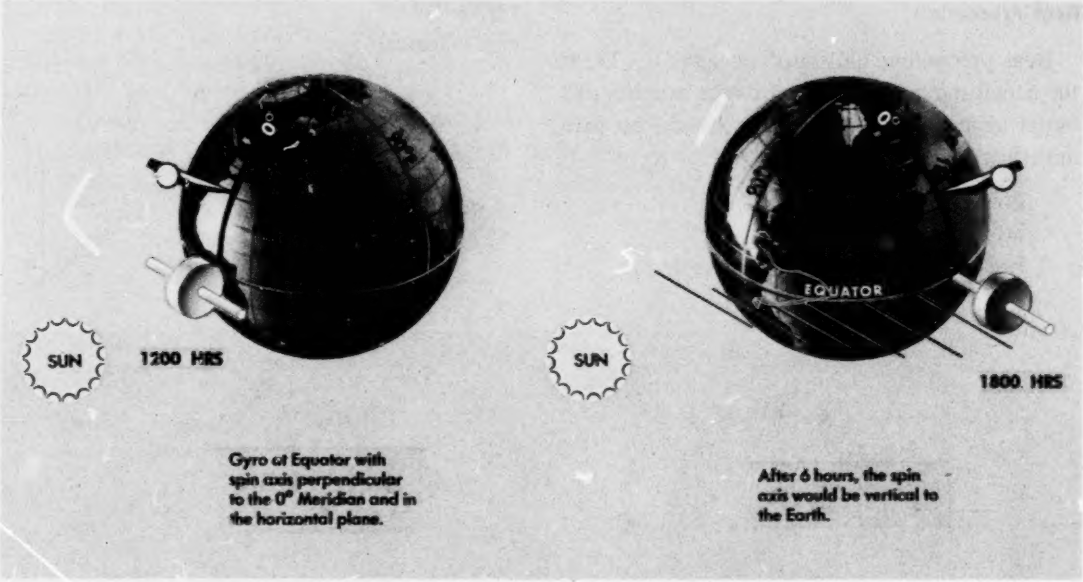

0°
SUN
1200 HRS
Gyro at Equator with spin axis perpendicular to the 0° Meridian and in the horizontal plane.
0°
EQUATOR
SUN
1800 HRS
After 6 hours, the spin axis would be vertical to the Earth.

Figure 19-15. Direction of Spin Axis Affects Earth Rate Precession

As a result of the improved quality of equipment now being used, real precession or gyro drift is considered to be negligible. Some compass systems have a real precession rate of less than 1° per hour. Electrical or mechanical forces are intentionally applied by erection or compensation devices to align the gyro spin axis in relation to the earth's surface. In this manner the effects of gyro drift and apparent precession are eliminated and the gyro can then be used as a reliable reference.

Apparent Precession

The spin axis of a gyro remains aligned with a fixed point in space, while the navigator's plane of reference changes, making it *appear* that the spin axis has moved. Apparent precession is this *apparent* movement of the gyro spin axis from its initial alignment.

EARTH RATE PRECESSION. Earth rate precession is caused by the rotation of the earth while the spin axis of the gyro remains aligned with a fixed point in space.

Earth rate precession is divided into two components. The tendency of the spin axis to tilt up or down from the horizontal plane of the observer is called the vertical component. The tendency of the spin axis to drift around laterally; i.e., to change in azimuth, is called the horizontal component.

Generally, when earth rate is mentioned, it is the horizontal component which is referred to, since the vertical component is of little concern to the navigator.

A gyro, located at the north pole with its spin axis initially aligned with a meridian, appears to turn 15.04° per hour in the horizontal plane, because the earth turns 15.04° per hour. As shown in figure 19-14A, the apparent relationship between the Greenwich meridian and the gyro spin axis will change by 90° in six hours, though the spin axis is still oriented to the same point in space. Thus, apparent precession at the pole equals the rate of earth rotation.

At the equator, as shown in figure 19-14B, no earth rate precession occurs *in the horizontal plane* if the gyro spin axis is still aligned with a meridian and is parallel to the earth's spin axis.

When the gyro spin axis is turned perpendicular to the meridian, as illustrated in figure 19-15, maximum earth rate precession occurs *in the vertical component*. But the directional gyro does not precess vertically because of the intentional restriction of the gyro movement in any but the

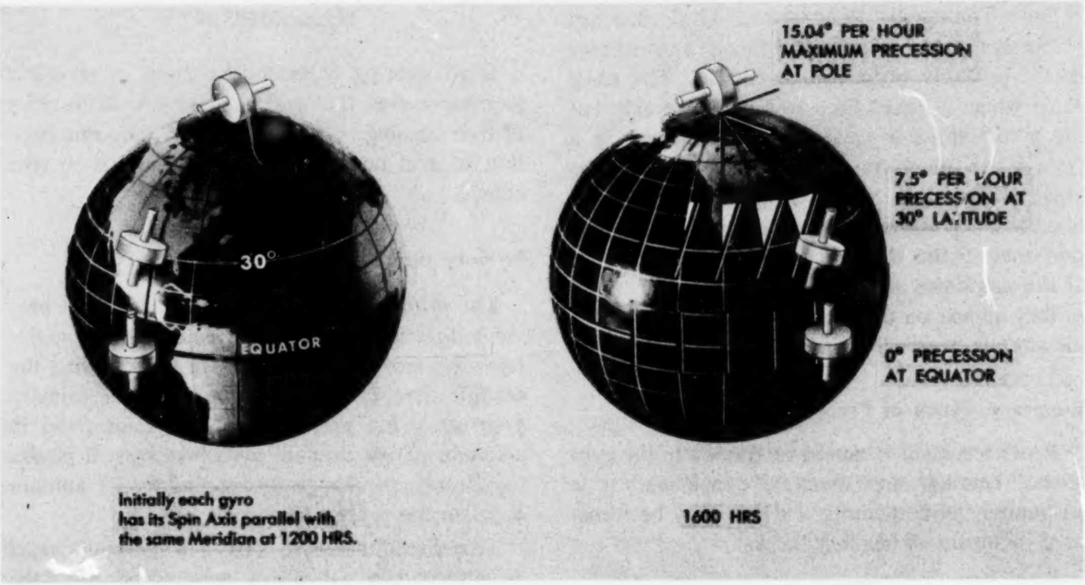

15.04° PER HOUR MAXIMUM PRECESSION AT POLE
30°
EQUATOR
7.5° PER HOUR PRECESSION AT 30° LATITUDE
0° PRECESSION AT EQUATOR
Initially each gyro has its Spin Axis parallel with the same Meridian at 1200 HRS.
1600 HRS

Figure 19-16. Earth Rate Precession Varies According to Latitude

horizontal plane. Thus, for practical purposes, earth rate precession is only that precession which occurs in the horizontal plane. Figure 19-15 illustrates earth rate precession at the equator for six hours of time.

Earth rate precession varies between 15.04°/hr at the poles and 0°/hr at the equator. It is computed for any latitude by multiplying 15.04° times the sine of the latitude.

For example, at 30° N, the sine of latitude is 0.5 The horizontal component of earth rate is, therefore, 15°/hour right × —0.5 or 7½°/hour right at 30° N as shown in figure 19-16.

Obviously, if the gyro is precessing relative to the steering datum of grid or true north, an aircraft steered by the gyro will be led off heading steadily at the same rate. To compensate for this precession, an artificial real precession is induced in the gyro to counteract the earth rate. At 30° north latitude earth rate precession is equal to 15° × sin lat (.5) = 15 × .5 or 7.5° per hour to the right.

Hence, if at 30° north latitude a real precession of 7.5° left per hour is induced in the gyro, it will exactly balance and offset earth rate effect. In ordinary gyros a weight is used to produce this effect, but since it is fixed, the correction is good for only one latitude. The latitude chosen is normally the mean latitude of the area in which the aircraft will operate. Gyros, such as that of the N-1 compass system, have a latitude setting knob which the navigator may use to adjust for the earth rate corrections.

EARTH TRANSPORT PRECESSION (HORIZONTAL PLANE). This form of apparent precession results from transporting a gyro from one point on the earth's surface to another. The gyro spin axis *appears* to move because the aircraft, flying over the curved surface of the earth, changes its attitude in relation to the gyro's fixed point in space (see figure 19-17).

Earth transport precession causes the gyro spin axis to move approximately one degree in the horizontal plane for each true meridian crossed.

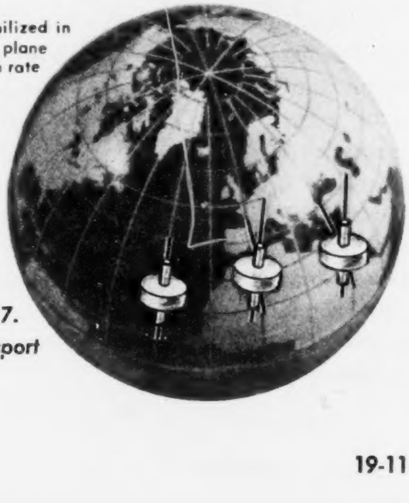

Gyro stabilized in horizonal plane and earth rate corrected

Figure 19-17. Earth Transport Precession

GRID TRANSPORT PRECESSION. Grid transport precession exists because meridian convergence is not precisely portrayed on charts. The navigator wants to maintain a *straight* line track, but the gyro follows a great circle track which is a *curved* line on a chart. The rate at which the great circle track curves away from a straight line track is *grid transport precession.* This is proportional to the difference between convergence of the meridians as they appear on the earth and as they appear on the chart, and the rate at which the aircraft crosses these meridians.

Summary (Types of Precession)

Real precession is caused by friction in the gyro gimbal bearings and dynamic unbalance. It is an unpredictable quantity and can only be measured by means of heading checks.

Earth rate precession is caused by the rotation of the earth. It can be computed in degrees per hour with the formula: 15.04 × sine latitude (for practical purposes 15°/hr is used). It is to the right in the Northern Hemisphere, to the left in the Southern Hemisphere. All gyros are corrected to some degree for this precession, many by means of a latitude setting knob.

Earth transport precession (horizontal plane) is an effect caused by using true north as a steering reference. It can be computed using the formula (change longitude/hr × sine midlatitude). The direction of the precession is a function of the true course of the aircraft. If the course is 0°-180°, precession is to the right; if the course is 180°-360°, precession is to the left. This precession effect is avoided by using grid north as a steering reference.

Grid transport precession is caused by the fact that the great circles are not portrayed as straight lines on plotting charts. The navigator tries to fly his straight pencil-line course, the gyro a great circle course. The formula for grid transport precession is change longitude/hr (sin lat$-\eta$), where η is the map convergence factor. The direction of this precession is a function of the chart used, the latitude, and the true course. Direct substitution into the formula will produce an answer valid for easterly flights; i.e., 0° — 180°. For westerly courses, the sign of the answer must be reversed.

GYRO STEERING

Gyro steering is much the same as magnetic steering, except that grid heading is used in place of true heading. Grid heading has the same relation to grid course as true heading has to true course.

Primary and Secondary Gyros

The primary steering gyro in most aircraft provides directional data to the autopilot and maintains the aircraft on a preset heading. When the aircraft alters heading, it turns about the primary gyro while the gyro spin axis remains fixed in azimuth. If the primary gyro precesses, it causes the aircraft to change its heading by an amount equal to the precession.

The directional gyro (DG) is normally used as a secondary (standby) gyro; it becomes the primary steering reference when the primary gyro malfunctions. However, the DG does not provide directional data to the autopilot. The precession of the DG is normally rated, whether or not it is used as a heading reference.

The Gyro Log

The gyro log is a record of the precession occurring in two gyros, the primary steering instrument that is being used to direct the aircraft, and a secondary gyro that serves as a standby, or backup, instrument.

At the beginning of a grid navigation leg, the navigator turns the aircraft to the initial heading (IH). This is the desired heading (grid course ± drift) with half of the anticipated precession applied to it. Since it is the beginning of the grid navigation leg, no precession rate has been established; therefore, the initial heading is the same as the desired heading (DH). DH is recorded in block 7 and IH is recorded in block 9 of the gyro log shown in figure 19-18. In this example, the DH and IH are 246°. As soon as possible after departure, a celestial heading check is obtained to insure the aircraft is on the IH. The navigator records the time of the observation (1700) in block 1 and the celestial heading (246°) in block 2. If the celestial heading observation is not 246°, the aircraft is turned to the IH of 246° and the word "set" is recorded in block 3.

GRID HEADING INFORMATION	1. TIME (Z)	1700		1730		1800		1815		1830		1830 EXIT	
	2. CELESTIAL HEADING (GH)	246°		248°		247°		297°		298°		TH 200°	
	3. PRIMARY GYRO | SECONDARY GYRO	SET		246°	249°	245°	248°	SET		297°	298°	SET	
	4. PRECESSION			+2	-1	+2	-1			+1	0		
	5. HOURLY RATE			+4	-2	+4	-2			+4	0		
	6. AVERAGE HEADING FLOWN			247°		246°				297½°			
	7. DESIRED HEADING	246°		246°		242°		297°		297°			
	8. ½ PRECESSION FOR TIME ON NEXT LEG			-1		-½				-½			
	9. INITIAL HEADING	246°		245°		241½°		297°		296½°			

Figure 19-18. Gyro Log

The navigator should establish a pacing plan for fixing, heading checks, and rating the gyros. The gyro log illustrated was maintained while rating the gyros each half hour.

At 1730, another celestial check indicates a grid heading of 248°, but the primary gyro still indicates 246°. In block 3, the navigator records the primary gyro reading (246°) and the DG reading (249°). The navigator now computes the gyro precession (GP) for both instruments by use of the formula:

GP (block 4) = GH − gyro reading

248° − 246° = +2° precession for the primary gyro

248° − 249° = −1° precession for the DG. Because these precessions occurred over a half-hour period, the hourly precession rates are:

+4° per hour for the primary gyro. (block 5)

−2° per hour for the DG. (block 5)

When gyro precession is plus, precession is to the right; when it is minus, precession is to the left.

The navigator now computes average heading flown for this time period using the following formula:

$$\text{Average heading} = \frac{\text{IH} + \text{FH}}{2} \quad \text{(final heading)}$$

$$= \frac{246^\circ + 248^\circ}{2}$$

$$= 247^\circ$$

The final heading (FH) is the last celestial grid heading obtained for the rating period. Since the navigator started on an IH of 246° and ended on a FH of 248°, his average heading flown is 247° (block 6).

If a fix were taken at 1730, a new desired heading would be determined from this position. But since a fix was not taken at 1730, the desired heading remains the same as that in the previous column of the log. In block 8, the navigator applies half of the primary gyro precession to the DH, for the next time period (30 minutes) *in the opposite direction of the precession* to compute a new IH (245°). At 1730, the aircraft is on a grid heading of 248°. To attain the new IH, the aircraft must be turned 3° left.

At 1800, the navigator obtains a fix, measures the new grid course, applies the wind, and determines the new desired heading (242°). Precession is computed and applied in the same manner previously described to obtain the new IH. In this example, the next checkpoint is only 15 minutes from the last rating period. Therefore, half of the anticipated precession applied in the opposite direction to the DH is −½°.

At 1815, the aircraft is turned toward the next checkpoint, the gyros are reset, and the ratings are restarted. The 1830 entry illustrates that the precession rate for the secondary gyro has changed as a result of the change in aircraft heading.

At 1830, a final fix is obtained and a turn toward destination is made. After the turn, the primary gyro is set and slaved to the magnetic heading, and the DG is also set to the magnetic heading.

SUMMARY

The USAF grid overlay and the free running gyro are used to overcome the difficulties of converging meridians and the unreliability of the magnetic compass when navigating in high (polar) latitudes. When gyro steering is used, the navigator maintains a gyro log and records the precession of both the primary and secondary gyros. The gyro log provides the navigator with the information necessary to predict values when it is impossible to obtain heading checks because of overcast conditions or twilight. By maintaining a log on the secondary gyro, the navigator can change gyros in case of malfunction of the primary gyro. He uses the information recorded in the gyro log in conjunction with the Navigator's Log (AF Form 21) to plot positions and compute winds, headings, alterations, and ETAs. The navigator must execute the proper correlation between his log and the gyro log to accomplish grid navigation successfully.

CHAPTER 20

Pressure Differential Techniques

Pressure differential flying, previously known as pressure pattern flying, involves a number of techniques, all of which have one common feature; they are designed to make maximum use of forecast and inflight information relative to the pressure field at the cruising level of the aircraft. Since pressure information is more easily obtained during flight than wind information, and since it is also more accurately forecast than wind information, pressure differential techniques, where applicable, provide the navigator a simple and accurate aid to navigation.

When used in the air, pressure pattern techniques make available two aids to navigation: *Bellamy drift* and the *pressure line of position* (PLOP). Both are obtained by substituting certain inflight information into a basic formula—neither requires any visual reference, special equipment, nor ground equipment.

Bellamy drift supplies net drift over a past period and, hence, information as to the track of the aircraft. It is most useful over water, and particularly during poor visibility and when radio aids are not available. The PLOP is a line of position as valid as any other type of LOP and considerably easier to obtain under difficult flight conditions. It can be combined with another type of LOP for a fix, and can be used to find MPPs. It is advanced and retarded by the usual methods.

CONSTANT PRESSURE SURFACE

Pressure differential navigation is based on the meteorological formula for the geostrophic wind, modified for flying a constant pressure surface. The constant pressure surface is one on which the pressure is the same everywhere, although its height above sea level may vary from point to point as shown in figure 20-1. It is a surface on which a constant reading will be indicated on the pressure altimeter.

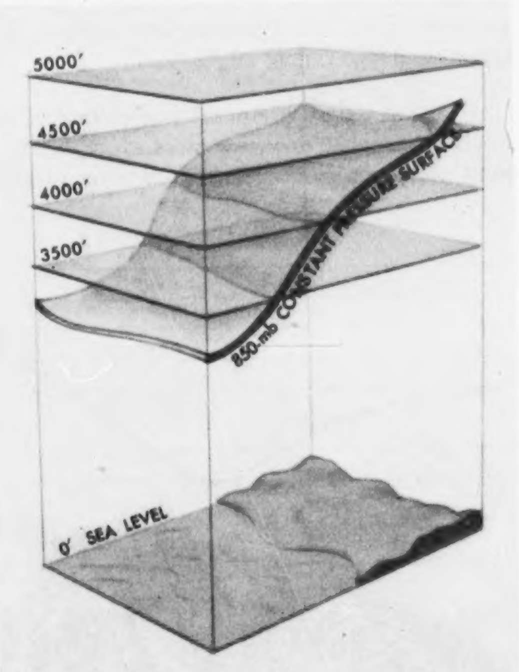


Figure 20-1. Constant Pressure Surface

Constant Pressure Chart

A constant pressure surface is shown on a constant pressure chart on which lines are drawn connecting points of equal height above sea level. These lines have the same significance as contour

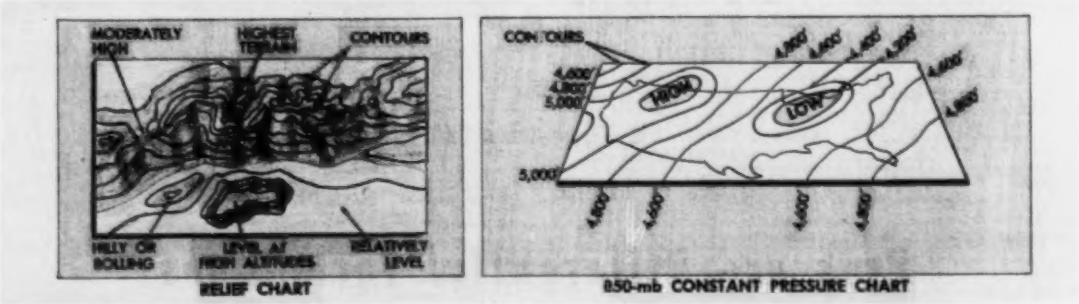

MODERATELY HIGH
HIGHEST TERRAIN
CONTOURS
HILLY OR ROLLING
LEVEL AT HIGH ALTITUDES
RELATIVELY LEVEL
RELIEF CHART
CONTOURS
4,600'
4,800'
5,000'
HIGH
LOW
5,000'
4,800
4,600
4,600
4,800
850-mb CONSTANT PRESSURE CHART

Figure 20-2. Contours

lines on maps of land areas, and hence, they are also termed *contours* (figure 20-2).

An aircraft flying with a constant indication on the pressure altimeter will automatically follow the configuration of the constant pressure surface, and in so doing, will change its true height as the contours change (figure 20-3).

Areas where the constant pressure surface forms troughs are termed *lows,* and areas where the constant pressure surface is peaked are termed *highs.* These configurations correspond to the highs and lows of the familiar surface chart and their circulation follows the same familiar patterns. Intersections of mean sea level by constant pressure surfaces form *isobars,* and intersections of a constant pressure surface by planes parallel to mean sea level form *contours* (analogous to geographic contours). A comparison of isobars and contours is shown in figure 20-4. The geostrophic wind will blow along the contours of a constant pressure chart just as it blows along the isobars of a constant level chart.

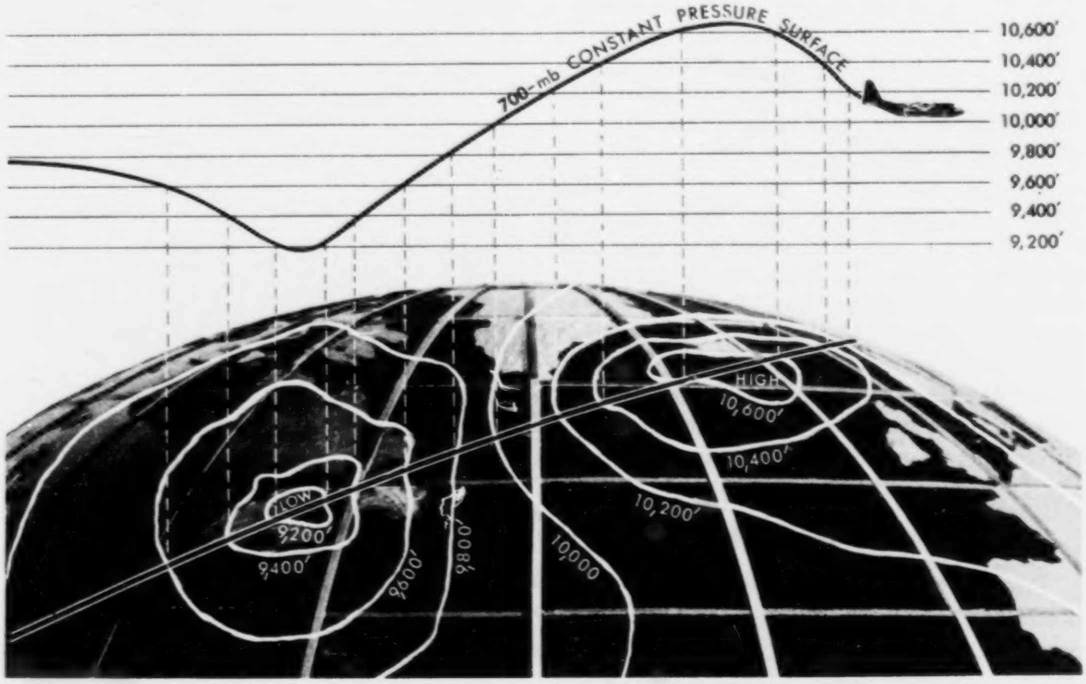

700-mb CONSTANT PRESSURE SURFACE
10,600'
10,400'
10,200'
10,000'
9,800'
9,600'
9,400'
9,200'
HIGH
10,600'
10,400'
10,200'
10000
9800'
9600'
LOW
9200'
9400'

Figure 20-3. Changing Contours of Constant Pressure Surface

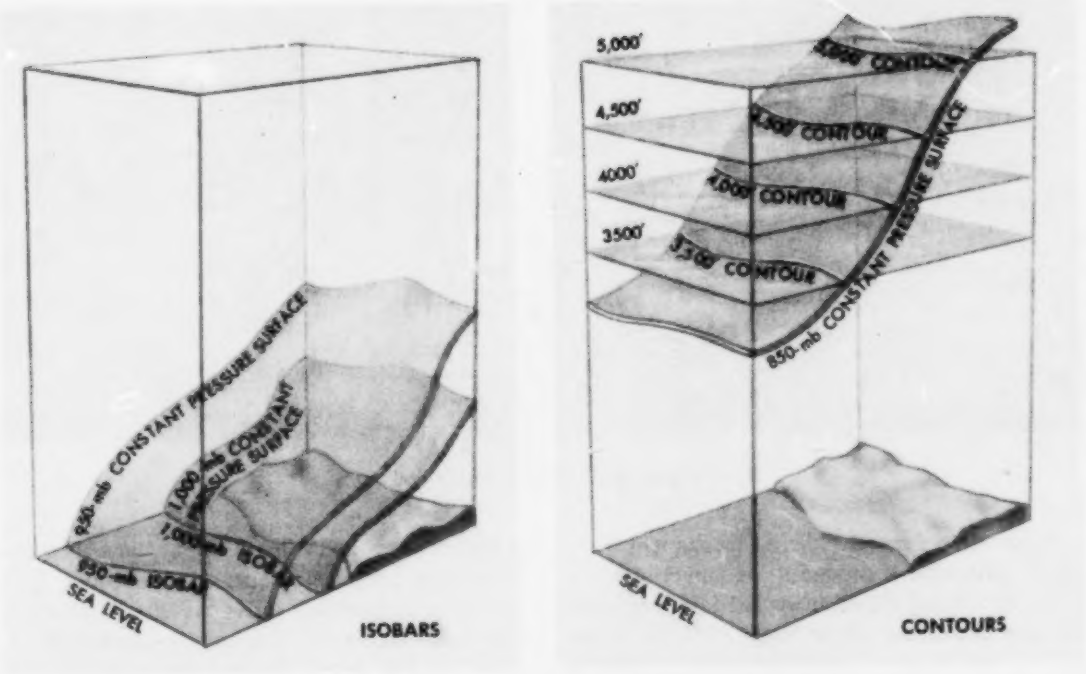

950-mb CONSTANT PRESSURE SURFACE
1,000-mb CONSTANT PRESSURE SURFACE
1,000-mb ISOBAR
950-mb ISOBAR
SEA LEVEL
ISOBARS
5,000'
4,500'
4000'
3500'
5,000' CONTOUR
4,500' CONTOUR
4,000' CONTOUR
3,500' CONTOUR
850-mb CONSTANT PRESSURE SURFACE
SEA LEVEL
CONTOURS

Figure 20-4. Comparison of Isobars and Contours

Geostrophic Wind

The atmosphere will try to regain a balanced condition whenever any disturbing influences are exerted upon it. As the sun's energy acts to bring about an unequal distribution of air mass over the earth's surface, the atmosphere reacts to restore the equal distribution of that air mass. Since the sun's rays are continuously affecting the atmosphere, the state of equilibrium is never reached and atmospheric mass is always unequally distributed over the earth. Atmospheric pressure, therefore, varies from point to point at the surface depending on the mass of air above the area considered. The difference in pressure per unit distance is known as the *pressure gradient* or more commonly as the *slope* of the pressure field (see figure 20-5).

Pressure gradient force and Coriolis combine to produce the geostrophic wind. The geostrophic wind assumes straight and parallel contours and exists above the level of earth-created friction. If centrifugal force due to curved contours is considered, the resultant wind is called the *gradient wind*.

The speed of the geostrophic wind is proportional to the spacing of the contours (or isobars). Closely spaced contours form a steep slope (higher gradient) and produce a stronger wind. Widely spaced contours or isobars produce relatively weak winds.

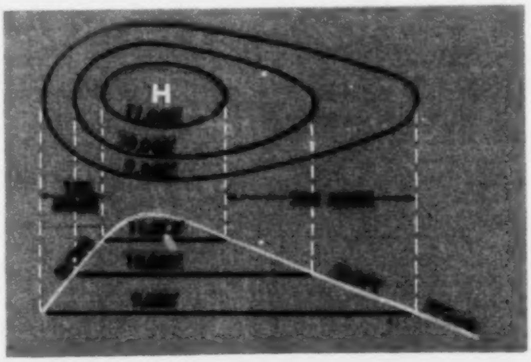


Figure 20-5. Pressure Gradient

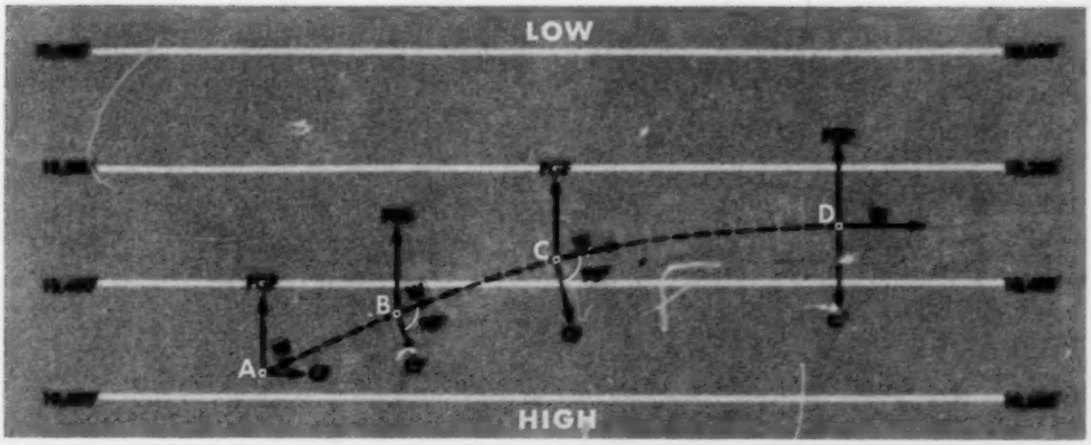


Figure 20-6. Geostrophic Wind

Figure 20-6 illustrates the manner in which the geostrophic wind is produced. A parcel of air at point *A* is being impelled toward lower pressure (*L*) by pressure gradient force (*PGF*). If the parcel were at rest, Coriolis force (*CF*) would be zero. But since the parcel is being initially moved across the contours toward lower pressure, Coriolis force comes into play, deflecting the parcel to the right. The resultant of the two forces is wind (*W*). At point *B*, the parcel continues to move and to accelerate, causing Coriolis force to increase. This action in turn deflects the parcel further to the right. At point *C*, the acceleration of the parcel continues to increase the magnitude of Coriolis force, producing further deflection of the parcel to the right. But at point *D*, pressure gradient force and Coriolis force have become equal in magnitude and opposite in direction. Unless other accelerating forces are introduced from this point on, the parcel continues on indefinitely, travelling parallel to the contours at its attained velocity. At point *D*, it is a portion of the geostrophic wind.

This wind is blowing parallel to the contours with lower pressure to the left of the direction of motion and higher pressure to the right. *Buys-Ballot's Law* states that in the Northern Hemisphere with one's back to the wind, lower pressure is to the left (see figure 20-7). The reverse is true in the Southern Hemisphere, where Coriolis deflection is to the left.

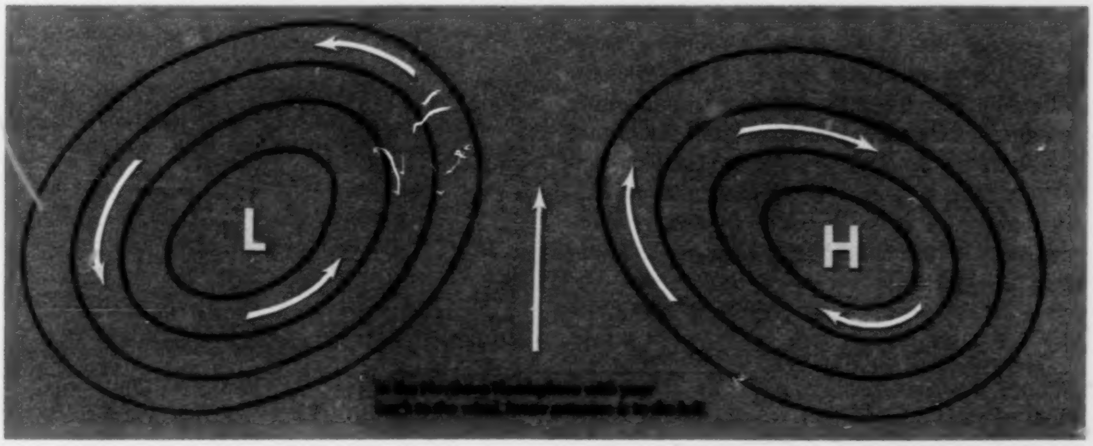


Figure 20-7. Buys-Ballot's Law

If the geostrophic wind is to be an accurate approximation of the actual wind, it is essential that contours be relatively straight and parallel, and that no distortion be introduced through surface friction. A minimum of two to three thousand feet of altitude above the surface usually guarantees an accurate geostrophic wind. In the area of the equator (20° N to 20° S), Coriolis force approaches zero, thereby invalidating the geostrophic wind as a useful factor in navigation; but pressure differential navigation is reliable in midlatitudes and polar areas.

PRESSURE COMPUTATIONS AND PLOTTING

In determining position (PLOP) or drift (Bellamy drift) by pressure differential techniques, the navigator makes use of the crosswind component of the geostrophic wind over a given period of time. The determination of the crosswind component of the geostrophic wind requires specific data for use in a formula, which, when solved, will give the direction and displacement effect of the pressure system through which the aircraft has flown. This resultant is called "ZN." To solve the ZN formula, the navigator must understand how to obtain and apply such special factors as "D" soundings, effective TAS, effective air path, effective air distance, and "K" values.

"D" Soundings

The symbol "D" stands for the difference between the true altitude of the aircraft and the pressure altitude of the aircraft. It is expressed in feet as a plus or minus value. An absolute altimeter is normally used to measure true altitude on overwater flights, and the pressure altimeter is used to measure the pressure altitude. To determine the correct D sounding, assign a plus (+) to true altitude, a minus (—) to pressure altitude, and algebraically add the two. The correct sign can be applied by remembering the key word, TAMPA: True Altitude Minus Pressure Altitude.

The first D sounding is obtained at the fix when the pressure differential navigation leg is started. It is called D_1. The second D sounding, D_2, is obtained at the time of the intended pressure LOP. The value, D_2-D_1, is an expression of the slope (pressure gradient) experienced by the aircraft. By algebraically subtracting D_1 from D_2, the navigator determines the change in aircraft true altitude between D_1 and D_2. When this altitude change is compared with the distance flown, the resulting values becomes an expression of the slope. A large value of D_2-D_1 indicates a steep slope; a small value of D_2-D_1 indicates a gentle slope. The sign of D_2-D_1 indicates whether the aircraft has been flying up slope (+) or down slope (—).

The D sounding for the next position is called D_3; the slope experienced between D_2 and D_3 is expressed as D_3-D_2. For consecutive positions, it becomes D_4-D_3, D_5-D_4, etc. If D_2 is believed unreliable, D_3 may be compared with D_1.

To obtain an accurate D sounding, it is advisable to take several readings, obtain the D (difference) for each reading, and arrive at a D sounding for the *midtime* of the readings. This method readily identifies discrepancies in reading. In addition, when any D sounding varies by 40 feet or more from the average of the other soundings, discard it and use the average of the remaining D soundings. It is important to take readings carefully. An erroneous reading of either altimeter will produce an incorrect D sounding and consequently an inaccurate LOP. A gentle tapping of the pressure altimeter before reading it will reduce hysteresis error.

The aircraft should maintain a constant pressure altitude to insure correct D soundings. If it becomes necessary to change altitude enroute, start a new D_1 at the new altitude.

Effective True Airspeed

In determining a pressure line of position, the navigator must compute the *effective true airspeed* (ETAS) from the last D sounding. The ETAS is the true airspeed that the aircraft would have had to make good, had it flown straight from D_1 to D_2. See figure 20-8. If the aircraft has maintained a constant true heading between D soundings, the effective true airspeed equals the average true airspeed. But if the aircraft has altered heading one or more times between the D soundings, the effective true airspeed is derived by drawing a straight line from the fix at the first D sounding to the final air position. This line is called the *effective air path* (EAP). Effective true airspeed is computed by measuring the *effective*

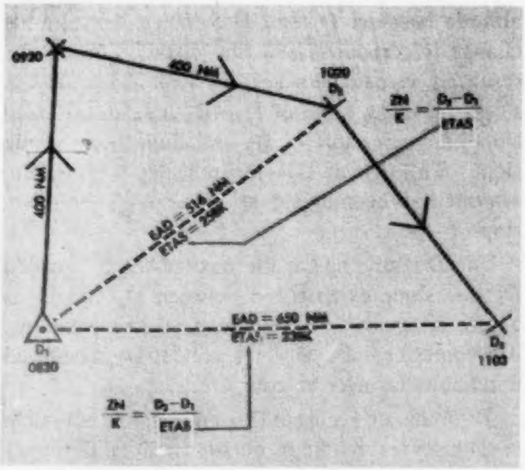


Figure 20-8. Effective True Airspeed

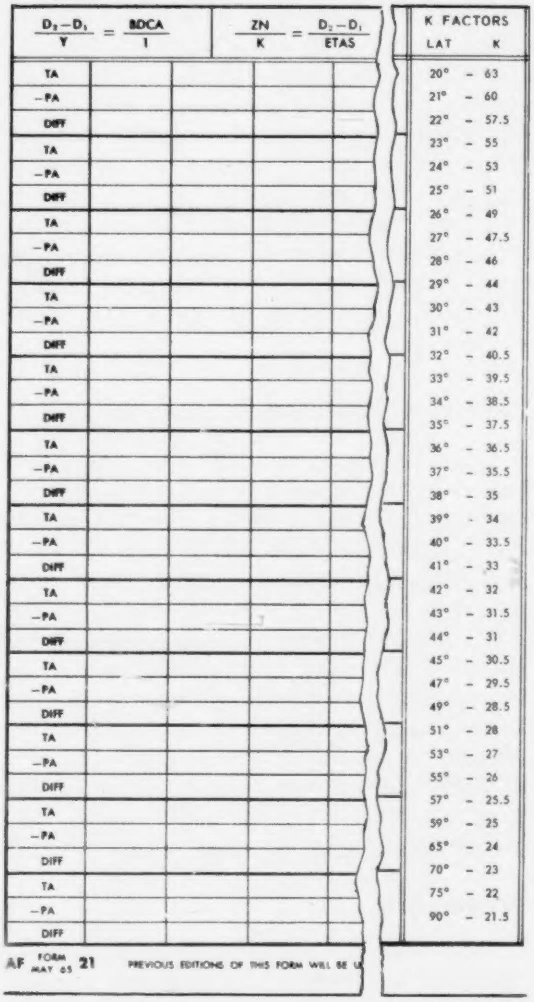
air distance (EAD) and dividing it by the elapsed time (in hours). In figure 20-8, an aircraft flew at 400 knots TAS from the 0820 fix to the 1020 air position via a dog-leg route. The effective air distance is 516 nautical miles; consequently, the effective true airspeed is 258 knots. In the illustration the navigator considered the D_2 sounding unreliable; therefore, he compared D_3 with the D_1 sounding.

K Factor

The constant (K) has been determined by taking into account the values of the Coriolis constant and the gravity constant for particular latitudes. K equals $\frac{21.49}{\sin \text{midlatitude}}$; where midlatitude is the average latitude between D_1 and D_2.

It is put in tabular form for the convenience of the navigator as shown in figure 20-9. In the table, this constant is plotted against latitude since Coriolis force varies with latitude. In using the ZN formula, the table is entered with midlatitude and the corresponding K is extracted.

Slope is properly expressed by vertical and horizontal displacement in the same units; however, the navigator expresses horizontal displacement in nautical miles and vertical displacement in feet. The K factor has been adjusted by a factor so that, with slope expressed in feet and distance in nautical miles, the geostrophic wind speed is computed in knots. Thus, the K factor cannot be used with statute miles to solve for the geostrophic wind in statute miles per hour.



	$\frac{D_2-D_1}{Y} = \frac{BDCA}{1}$		$\frac{ZN}{K} = \frac{D_2-D_1}{ETAS}$	
TA				
−PA				
DIFF				
TA				
−PA				
DIFF				
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−PA				
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K FACTORS

LAT	K
20°	63
21°	60
22°	57.5
23°	55
24°	53
25°	51
26°	49
27°	47.5
28°	46
29°	44
30°	43
31°	42
32°	40.5
33°	39.5
34°	38.5
35°	37.5
36°	36.5
37°	35.5
38°	35
39°	34
40°	33.5
41°	33
42°	32
43°	31.5
44°	31
45°	30.5
47°	29.5
49°	28.5
51°	28
53°	27
55°	26
57°	25.5
59°	25
65°	24
70°	23
75°	22
90°	21.5

AF FORM MAY 65 21 PREVIOUS EDITIONS OF THIS FORM WILL BE U

Figure 20-9. K Factors Table from AF Form 21

Crosswind Displacement (ZN)

ZN is a displacement value derived from soundings at two air positions. It is the displacement from the straight line air path between the soundings. Therefore a PLOP must be drawn parallel to the effective air path.

The ZN equation

$$ZN = \frac{K\,(D_2-D_1)}{ETAS}$$

can be rearranged for convenient solution on the DR computer as follows:

$$\frac{ZN}{K} = \frac{D_2-D_1}{ETAS}$$

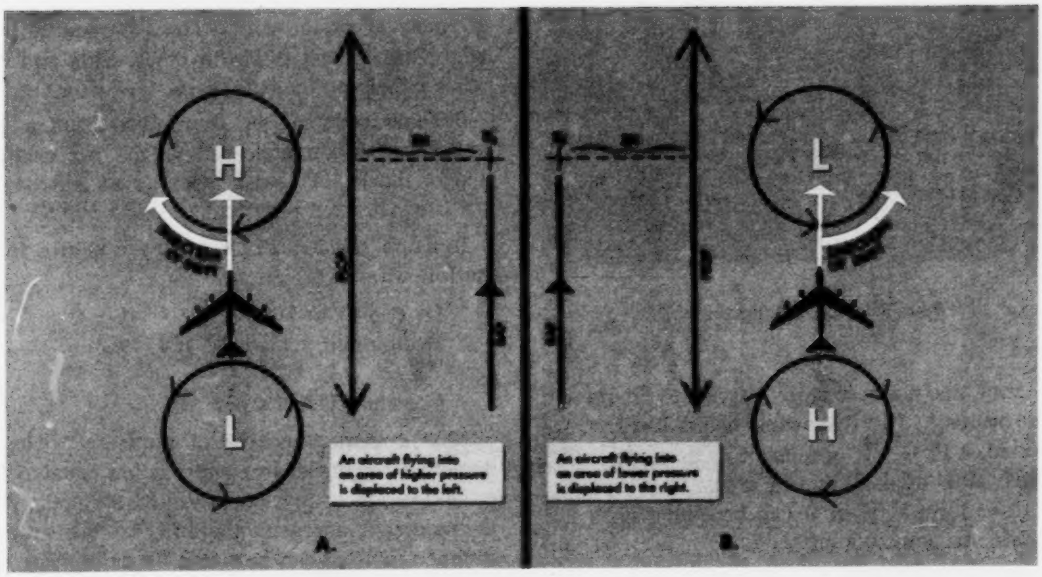

H
L
An aircraft flying into an area of higher pressure is displaced to the left.
A.
L
H
An aircraft flying into an area of lower pressure is displaced to the right.
B.

Figure 20-10. ZN Displacement in Northern Hemisphere

On newer DR computers, such as the MB-4, a subscale of latitude has been constructed opposite the values for K factors on the minutes scale. A table of K factors is not needed when these computers are used. Printed instructions on the face of these computers specify that, to compute crosswind component, set air miles flown (effective air distance) on the minutes scale opposite D_2—D_1 on the miles scale. The crosswind component (V_n) is not to be confused with crosswind displacement (ZN). The crosswind component (V_n) is crosswind velocity in knots. This component (V_n) must then be multiplied by the elapsed time between D_2 and D_1, in order to compute the crosswind displacement (ZN). If effective true airspeed is substituted for air miles flown (effective air distance) on the MB-4 computer, the ZN can be read over the K factor (or latitude on the subscale).

PRESSURE LINE OF POSITION (PLOP)

Once ZN is determined, it can be plotted to obtain a *pressure line of position* (PLOP).

The direction of this displacement must also be determined; that is, the navigator must determine whether the aircraft has drifted right or left of the effective air path. Recall that wind circulation is clockwise around a high and counterclockwise around a low in the northern Hemisphere; the opposite is true in the Southern Hemisphere. Thus, in the Northern Hemisphere, when the value of D *increases* (a positive D_2—D_1), the aircraft is flying into an area of higher pressure and the drift is left (see figure 20-10A). When the value of D *decreases* (a negative D_2—D_1), the aircraft is flying into an area of lower pressure and the drift is right (see figure 20-10B).

Always plot the PLOP *parallel to the effective*

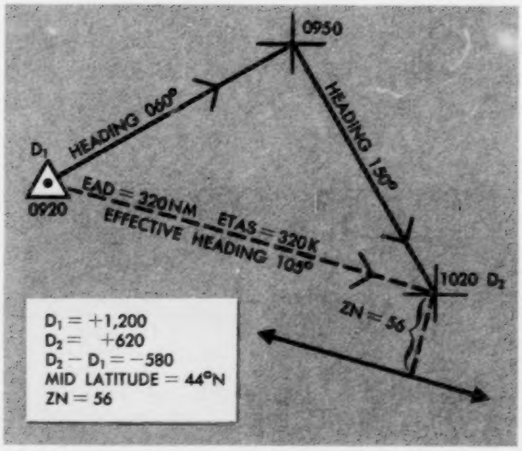

0950
D₁
HEADING 060°
HEADING 150°
0920
EAD = 320NM ETAS = 320K
EFFECTIVE HEADING 105°
1020 D₂
ZN = 56
D₁ = +1,200
D₂ = +620
D₂ − D₁ = −580
MID LATITUDE = 44°N
ZN = 56

Figure 20-11. Plotting the PLOP

air path, and not necessarily parallel to the present true heading. This is shown in figure 20-11. Once plotted, a PLOP is used in the same manner that any LOP is used. It can be crossed with another LOP to form a fix or it can be used with a DR position to construct an MPP.

BELLAMY DRIFT

Bellamy drift is a mean drift angle calculated for a past period of time. It is named for Dr. John Bellamy who first demonstrated that drift could be obtained from the use of pressure differential information. Bellamy drift is used in the same way as any other drift reading.

The primary advantage of Bellamy drift is its independence from external sources. An undercast, overcast, or poor radio transmission will not adversely affect the drift. The accuracy of Bellamy drift is comparable to other drifts and depends largely on the skill of the navigator.

Bellamy drift can be determined from a ZN ground distance triangle without the intermediate step of the PLOP, but it is easier to understand if it is constructed graphically using a PLOP.

In figure 20-12, a PLOP has been plotted from the following information:

D_1 at a fix at 1000
D_2 at an air position at 1045
ZN = − 20 NM
Constant TH of 090°

Next, construct an MPP on the PLOP. This is done by swinging an arc, with a radius equal to the ground distance traveled, from the fix at the first D-reading to intersect the PLOP. The ground distance traveled can be found by multiplying the best known groundspeed (groundspeed by timing, metro groundspeed, etc.) by the time interval between readings. The mean track is shown by the line joining D_1 and the MPP. The mean drift is the angle between true heading and the mean track (8°R). Thus, the Bellamy drift is 8° right.

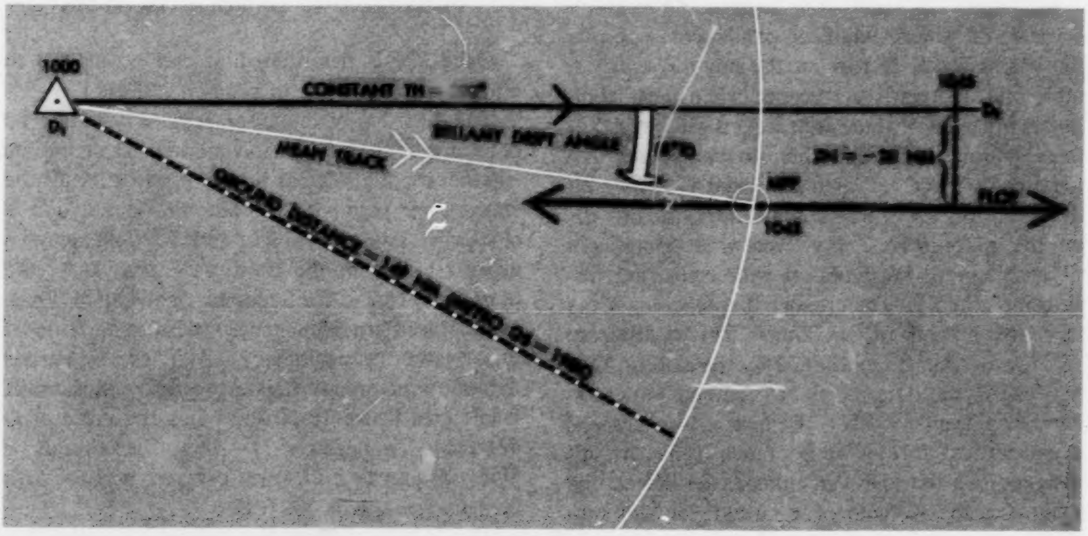

1000
D₁
CONSTANT TH = 090°
BELLAMY DRIFT ANGLE
(8°R)
MEAN TRACK
GROUND DISTANCE = 140 NM (METRO GS = 180)
1045
D₂
ZN = −20 NM
MPP
1045
PLOP

Figure 20-12. Solution of Bellamy Drift Using PLOP

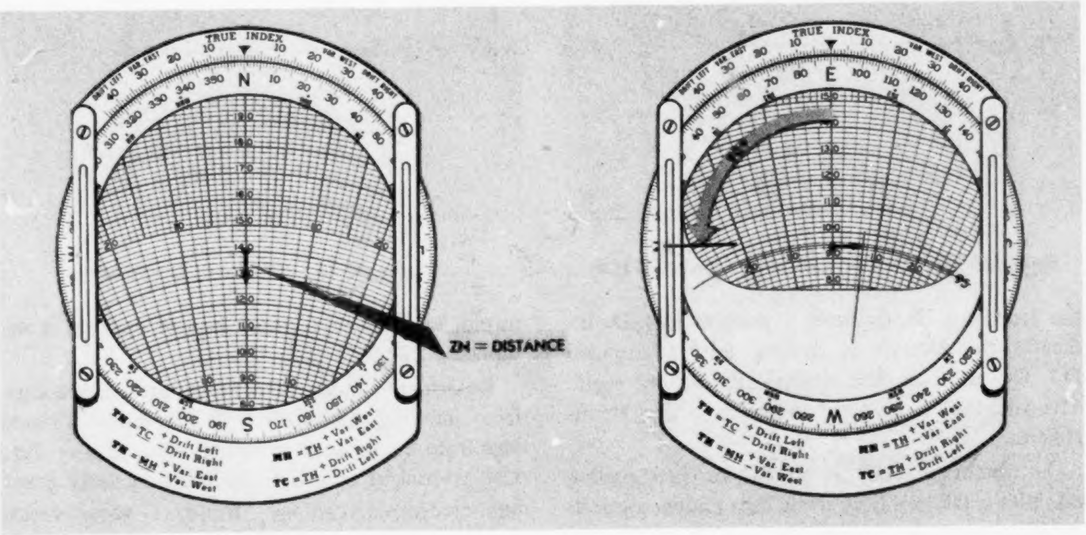

TRUE INDEX
N
S
E
W
ZN = DISTANCE
TH = TC + Drift Left − Drift Right
TH = MH + Var East − Var West
MH = TH + Var West − Var East
TC = TH + Drift Right − Drift Left

Figure 20-13. Computer Solution of Bellamy Drift

Computer Solution of Bellamy Drift

Solving the Bellamy drift angle on the DR computer is a relatively simple process. The center vertical line on the slide represents true heading. The ZN must be plotted at right angles to the true heading. This can be done by drawing the ZN vector down from the grommet and rotating the transparent face 90°. For convenience, one of the cardinal headings is placed under the true index when the ZN is drawn in to make it simple to rotate the face through 90°.

It makes no difference whether the face is turned to the right or left, as the sense of the drift is not taken from the DR computer. The sense is determined by the same considerations governing the plotting of the PLOP ($D_2 - D_1$ negative, Northern Hemisphere, drift right).

The slide is then positioned so that the ground distance is under the end of the ZN vector and the drift angle is read at the end of the ZN vector.

Example (figure 20-13)

Given: Northern Hemisphere
ZN = + 12.1
Time = 0:30
GS = 190 Knots

Find: Ground Distance = 95 NM
Drift = 7° left

Bellamy drift may also be determined on the slide rule side of the DR computer by placing the ZN over the ground distance and reading the Bellamy drift angle opposite 57.3. This can be set up in a formula as follows:

$$\frac{\text{BD}}{57.3} = \frac{\text{ZN}}{\text{Ground Dist. NM}}$$

The previous example would be set up as shown in figure 20-14. The answer 7.3 can be read over 57.3 on the minutes scale or under the index of the DRIFT CORR window.

The direction of Bellamy drift is determined in the same way that ZN direction is determined. In

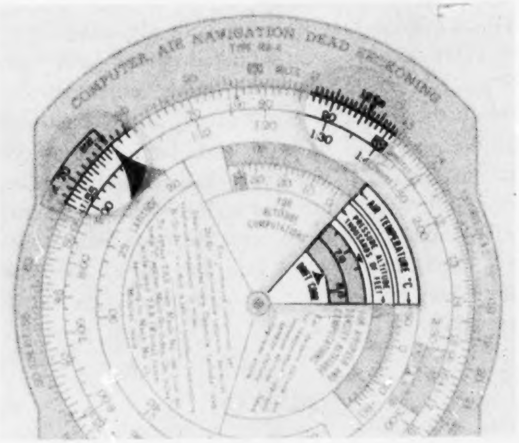

COMPUTER, AIR NAVIGATION, DEAD RECKONING
AIR TEMPERATURE °C

Figure 20-14. Mathematical Solution of Bellamy Drift

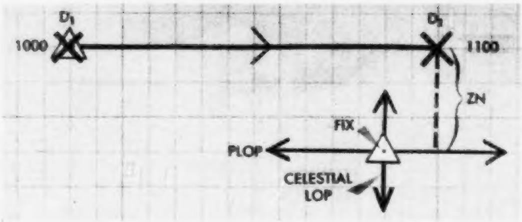


Figure 20-15. Fix Using PLOP and Celestial LOP

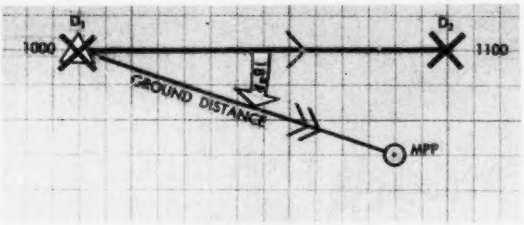


Figure 20-16. MPP by Bellamy Drift

the Northern Hemisphere, a positive $D_2—D_1$ indicates the aircraft is drifting left; a negative $D_2—D_1$ indicates the aircraft is drifting right. The situation is reversed in the Southern Hemisphere.

To obtain an MPP, apply BD to true heading and plot a DR position, using best known groundspeed.

Errors and Limitations of Pressure Differential Techniques

GROUND DISTANCE ERROR. In plotting an MPP from a PLOP, an error in ground distance will cause an error in the MPP and, hence, an error in the mean track. However, an error in the MPP will not substantially affect the accuracy of the drift angle.

TACTICAL LIMITATIONS. Bellamy drift has one main limitation. For drift to be determined on each leg of a flight by the Bellamy method, the heading taken up by the aircraft must be maintained long enough to permit a pair of soundings with a time separation of at least 20 minutes.

Some economy of effort will result if a sounding is taken immediately before or after a turn. This sounding may be used, with negligible error, as reference for determining drifts on both legs. Some error will be caused by the difference between the height of the constant pressure surface at the sounding position and the height at the turning point. If not more than a minute or two elapses between turn and sounding, however, the ZN is unlikely to be in error by more than a mile (assuming crosswind is less than 60 knots), and the effect on drift will be correspondingly small, especially if TAS is high.

SUMMARY

ZN is a displacement in nautical miles perpendicular to the effective air path. This means that airplot must be used and a known position is required at the time of D_1.

Determine the D-value by computing readings from the radio altimeter with simultaneous readings from the pressure altimeter, $D = TA - PA$. Use a series of comparisons to aid in picking out any erroneous readings. If any D-value varies by 40 feet or more from the average of the series, discard it and average the remaining values. Consistent errors in the altitudes will not affect the accuracy of the ZN, but changing the setting of either altimeter after the first D-reading will cause inaccuracy. Check the reference blip of the radio altimeter before each reading.

The ZN is obtained by using the equation

$$ZN = \frac{K(D_2—D_1)}{ETAS}$$

which can be rearranged for convenience in using the DR computer,

$$\frac{ZN}{K} = \frac{D_2—D_1}{ETAS}$$

Determine effective true airpseed by using the effective air distance and time. Measure effective air distance along a straight line between the two points in question. After the value of ZN is determined, plot the PLOP parallel to the effective air path. In the Northern Hemisphere, the sign of ZN is the sign of drift correction, and in the Southern Hemisphere, the sign of ZN is the sign of drift. Once the PLOP is plotted, treat it like any other LOP.

Though a PLOP is often preferred to BD, there are two main uses for Bellamy drift:

1. It is often computed to crosscheck the drift that is determined from a fix.
2. Bellamy drift may be plotted as an LOP and then crossed with an LOP from another fixing aid. Figure 20-15 shows a fix determined by use of a PLOP and a celestial LOP; figure 20-16 shows an MPP determined by Bellamy drift.

CHAPTER 21

Loran

The name *loran* is derived from the words LOng RAnge Navigation, which is an appropriate description of the hyperbolic system of electronic navigation. It provides lines of position over the surface of the earth. Over water, usable loran signals can be received during the day at ranges approaching a thousand miles and at night at ranges of approximately three thousand miles.

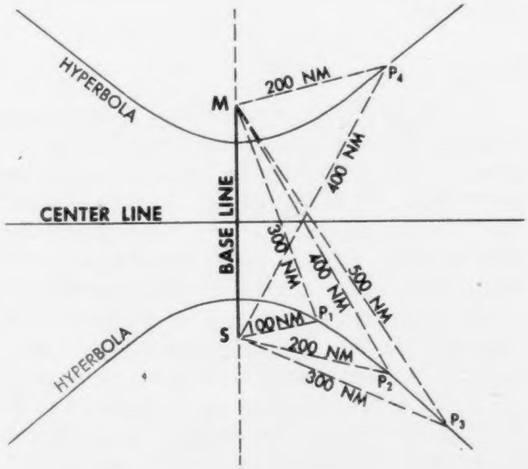
The relatively long range of loran is made possible by employing low and medium frequency radio waves. At these frequencies, radio waves are capable of following the curvature of the earth.

Loran lines of position can be crossed with each other, or with lines of position determined by any other means, to provide fixes. Unlike celestial lines of position, loran lines are stationary with respect to the earth's surface. Their determination is not dependent upon compass or chronometer, and it is not necessary to break radio silence to obtain them. It is possible to receive loran signals in all weather, except during very severe electrical disturbances. Observations can be made and a loran fix plotted in two to three minutes under good conditions. The accuracy of a loran fix is generally equal to or greater than that obtained from celestial observations.

Three types of Loran are currently in use. These are Loran-A, Loran-C, and Loran-D. Since Loran-C and Loran-D are sophisticated extensions of Loran-A, the basic principles of operation and theory of Loran are discussed using Loran-A. Following the discussion of Loran-A theory, Loran-C and Loran-D are introduced.

PRINCIPLES OF OPERATION

Since the speed of radio waves is virtually constant and quite accurately known, the time needed for a signal to travel a given distance can be determined with considerable accuracy. Conversely, the measurement of the time needed for a radio signal to travel between two points provides a measurement of the distance between them. All points having the same difference in distance from two stationary points, called foci, lie along an open curve called a *hyperbola.* Actually, there are two curves or parts to each hyperbola, as shown in figure 21-1, each representing the same time difference, but with the



AT P_1, 300 NM − 100 NM = 200 NM
P_2, 400 NM − 200 NM = 200 NM
P_3, 500 NM − 300 NM = 200 NM
P_4, 400 NM − 200 NM = 200 NM

Figure 21-1. Loran Hyperbolas

distance interchanged. Thus, the difference in the distances (200 NM) from the two stations is the same at points P_1, P_2, P_3, and P_4.

The Loran-A system consists of a series of synchronized pairs of radio transmitting stations which broadcast pulse signals similar to those used in radar, with a constant time interval between them. These transmitting stations are the foci. The aircraft has a combination radio receiver and time difference measuring device. The measurements made by this equipment are used for entering tables or charts to identify the hyperbola on which the receiver is located. (Because of the spheroidal shape of the earth, these lines differ slightly from true hyperbolas. This difference is considered in the computations upon which the loran tables and charts are based, but is generally ignored in a discussion of those aspects of the system in which it is not significant.)

Loran determines the difference in distance by measuring the time interval, in microseconds (μs), between the arrival of the first signal and the arrival of the second signal from a pair of synchronized transmitters. One of the two transmitters constituting a pair is designated the *master (M)*, the other the *slave (S)*. The direct line joining these two is called the *base line*. The continuations of this line beyond the transmitters are called the *base line extensions*. The perpendicular bisector of the base line is called the *center line*.

Delays

BASE LINE DELAY. If both signals were transmitted at the same instant, they would arrive together at any point along the center line. At any point nearer the master station, the master signal would arrive first, and at any point nearer the slave station, the slave signal would arrive first. Since both signals are alike, this arrangement would be unsatisfactory, as it would include an ambiguity which could be resolved only by knowing the approximate position of the receiver. Near the center line, reasonable doubt might exist as to which line to use. This ambiguity is eliminated by delaying transmission of the slave signal until the master signal arrives at the slave station. This also provides a means of synchronizing the signals, for the master signal is used to trigger the slave station. Radio waves travel at about 299,708 kilometers per second. Since this is equal to 161,829 nautical miles per second, the distance traveled in 1 μs is 0.162 nautical miles, or 6.18 μs are needed for a pulse to travel one nautical mile. Hence, the length of this delay is the time needed for the signal to travel the length of the base line, or in microseconds, 6.18 times the length of the base line in nautical miles. The length of the base line, and therefore the length of the delay, varies from one station pair to another. This delay is called the *base line delay*.

CODED DELAY. With the base line delay in use, the master station transmits a signal first. This signal travels outward in all directions. When this expanding wave front arrives at the slave station, the slave signal is transmitted. If no other delay were introduced, the signals would travel together along the slave base line extension, and the time difference would be zero. By the time the slave signal arrived at the master station, the master signal would be a distance away equal to twice the duration of the base line delay. With this arrangement, however, the time difference readings would be so small in some portions of the pattern that identity of each signal would not be apparent until the measurement was completed, or nearly so. To avoid this, a second delay is introduced. This is called the *coded (or coding) delay*. The effect of this delay is to *increase* all time difference readings by the amount of the coded delay, thus assuring a positive value throughout the pattern. The coded delay is also used as a security measure against compromise of the system during time of war.

CONTROLLED DELAY. In the cathode ray tube of the receiver-indicator, loran signals appear as pips on a time base. Measurement of the time interval between the two signals is made easier by dividing this time base into two halves, and putting the second half under the first. Measurement is then made as if the beginning of each trace represented the same instant. This does not introduce an error in the reading because a third delay, called *controlled delay* (also known as half pulse-repetition-rate delay), is introduced at the slave station. Transmission of the slave signal does not occur at the instant the master signal arrives, but at a later time, the wait being just half the interval between the arrival of one triggering master signal and the next. Hence, controlled delay does not change the reading, which still varies from the coded delay along the slave base line extension to twice the base line delay plus the coded delay along the master base line extension.

Controlled delay also insures that when the master signal is near the beginning of the top trace, the slave signal must be on the bottom trace. Whenever two signals appear on the bottom trace, the slave pulse is then to the left of the master.

ABSOLUTE DELAY. The total time difference between the transmission of the master signal and the transmission of the slave signal is called the *absolute delay*. It is equal to the sum of the base line, controlled, and coded delays. Figure 21-2 illustrates the timing sequence and delays of a Loran-A synchronized pair of radio transmitting stations.

Pulses

A Loran-A station is a pair of synchronized transmitters (master and slave) which alternately radiate short bursts of radio frequency energy. These pulses are unmodulated and are broadcast in all directions.

A Loran-A system consists of loran chains. Each chain consists of several stations as illustrated in figure 21-3. To prevent the signals of two chains near each other from conflicting, each chain is given a different frequency (channel) from one of the following:

Channel 1 - 1950 kHz
Channel 2 - 1850 kHz
Channel 3 - 1900 kHz
Channel 4 - 1750 kHz

Each chain transmits on one of these channels. Since a loran receiver can receive signals from more than one station within each chain, each station is assigned a different pulse recurrence rate. *Pulse recurrence rate (PRR)* is the number of pulses transmitted in one second (pulses per second). *Pulse recurrence time (PRT)* is the pause, in microseconds, between pulses.

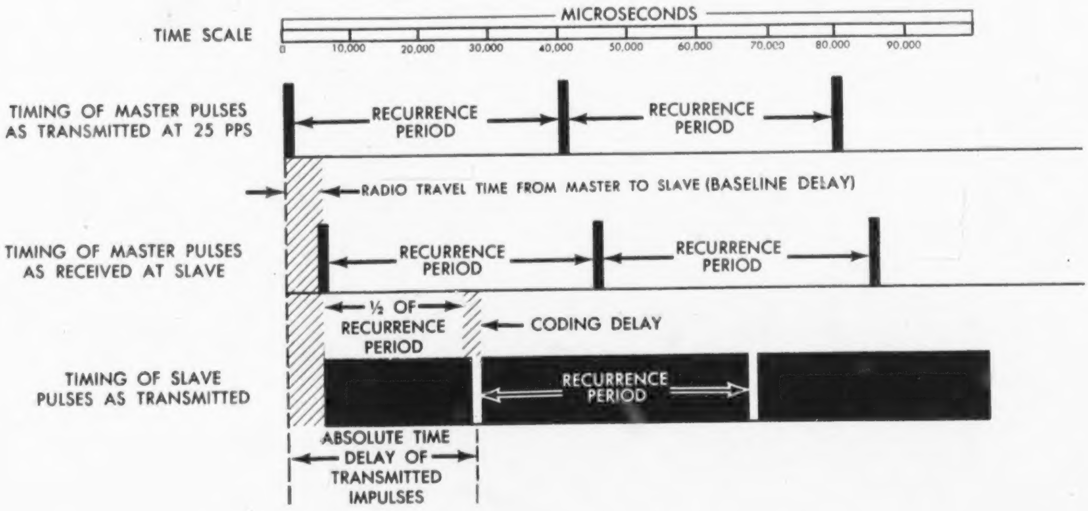
Each channel (frequency) is subdivided into basic PRRs and specific PRRs. The *basic PRR* is the approximate number of pulses transmitted per second; the *specific PRR* is the exact fractional change in the basic PRR. There are three basic PRRs:

Slow (S), 20 pulses per second (pps)
Low (L), 25 pulses per second (pps)
High (H), 33⅓ pulses per second (pps)

Eight specific PRRs are derived from each of the basic PRRs. Thus, each of the eight stations on the Slow, Low, or High basic PRRs operates on a different specific PRR. The table in figure 21-4 shows the basic PRRs, specific PRRs and PRTs.

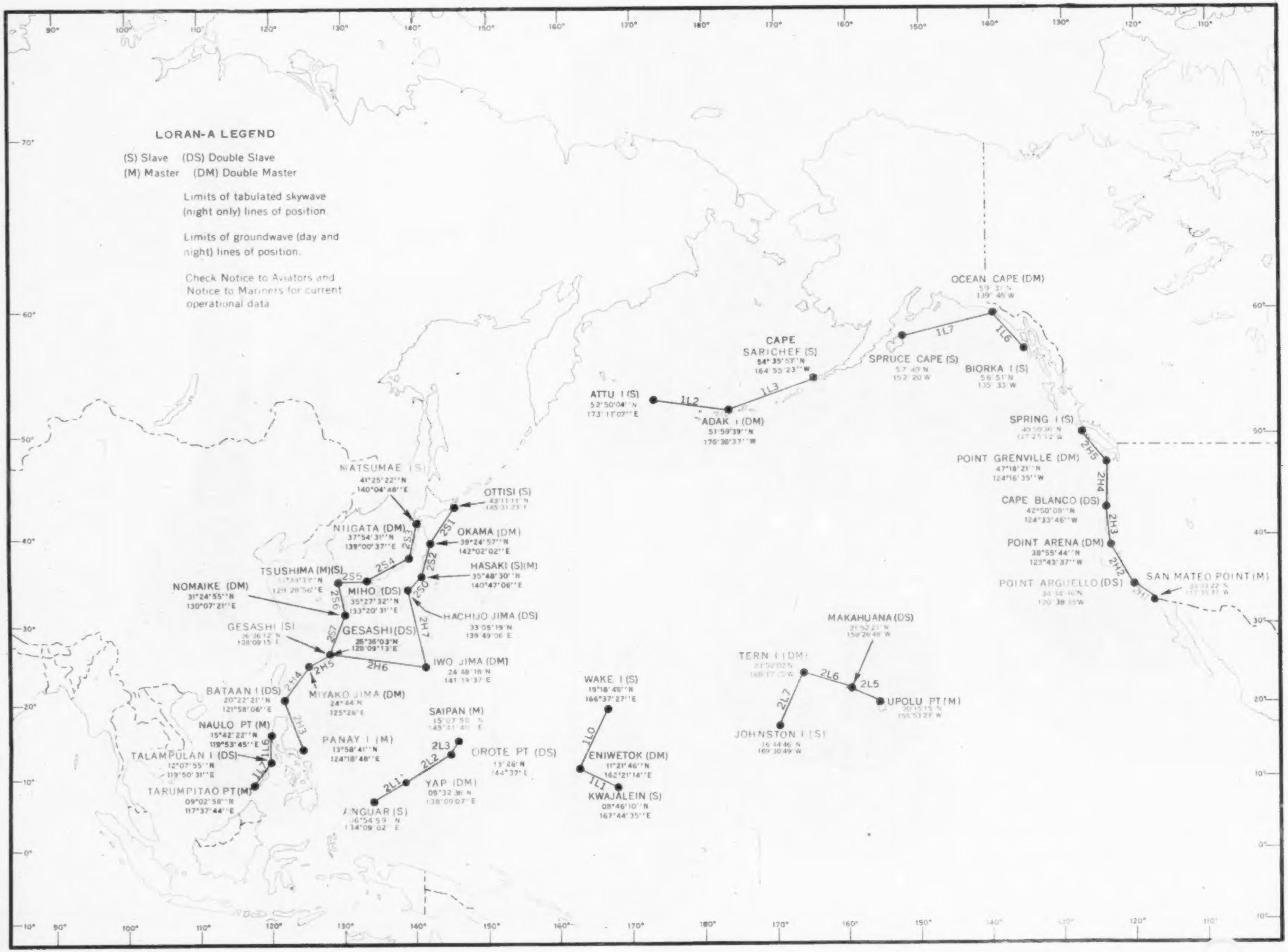
Each loran hyperbola is labeled with three characters which identify the station from which it originates. The first character indicates the channel, the second indicates the basic PRR, and the third indicates the specific PRR. A four-digit number follows the characters to indicate the time difference in microseconds for that hyperbola. A hyperbola labeled 2H1-1700 indicates that:

- The station operates on channel 2 (1850 kHz).
- The station has a High basic PRR (33⅓ pps).



MICROSECONDS
TIME SCALE
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
TIMING OF MASTER PULSES AS TRANSMITTED AT 25 PPS
RECURRENCE PERIOD
RECURRENCE PERIOD
RADIO TRAVEL TIME FROM MASTER TO SLAVE (BASELINE DELAY)
TIMING OF MASTER PULSES AS RECEIVED AT SLAVE
RECURRENCE PERIOD
RECURRENCE PERIOD
½ OF RECURRENCE PERIOD
CODING DELAY
TIMING OF SLAVE PULSES AS TRANSMITTED
RECURRENCE PERIOD
ABSOLUTE TIME DELAY OF TRANSMITTED IMPULSES

Figure 21-2. Loran-A Timing Sequence


LORAN-A LEGEND
(S) Slave (DS) Double Slave
(M) Master (DM) Double Master
Limits of tabulated skywave (night only) lines of position.
Limits of groundwave (day and night) lines of position.
Check Notice to Aviators and Notice to Mariners for current operational data
ATTU I (S) 52°50'04''N 173°11'07''E
ADAK I (DM) 51°59'39''N 176°38'37''W
CAPE SARICHEF (S) 54°35'53''N 164°55'23''W
SPRUCE CAPE (S) 57°49'N 152°20'W
OCEAN CAPE (DM) 59°31'N 139°46'W
BIORKA I (S) 56°51'N 135°33'W
SPRING I (S) 49°59'36''N 127°25'13''W
POINT GRENVILLE (DM) 47°18'21''N 124°16'35''W
CAPE BLANCO (DS) 42°50'09''N 124°33'46''W
POINT ARENA (DM) 38°55'44''N 123°43'37''W
POINT ARGUELLO (DS) 34°34'46''N 120°38'35''W
SAN MATEO POINT (M)
MAKAHUANA (DS) 21°52'21''N 159°26'46''W
TERN I (DM) 23°52'02''N 166°17'15''W
UPOLU PT (M) 20°15'15''N 155°53'23''W
JOHNSTON I (S) 16°44'46''N 169°30'49''W
WAKE I (S) 19°18'46''N 166°37'27''E
ENIWETOK (DM) 11°21'46''N 162°21'14''E
KWAJALEIN (S) 08°46'10''N 167°44'35''E
MATSUMAE (S) 41°25'22''N 140°04'48''E
OTTISI (S) 43°11'11''N 145°31'23''E
NIIGATA (DM) 37°54'31''N 139°00'37''E
OKAMA (DM) 39°24'57''N 142°02'02''E
HASAKI (S)(M) 35°48'30''N 140°47'06''E
TSUSHIMA (M)(S) 129°28'56''E
NOMAIKE (DM) 31°24'55''N 130°07'21''E
MIHO (DS) 35°27'32''N 133°20'31''E
HACHIJO JIMA (DS) 33°05'19''N 139°49'06''E
GESASHI (S) 26°36'12''N 128°09'15''E
GESASHI (DS) 26°36'03''N 128°09'13''E
IWO JIMA (DM) 24°48'18''N 141°19'37''E
MIYAKO JIMA (DM) 24°44'N 125°26'E
BATAAN I (DS) 20°22'21''N 121°58'06''E
NAULO PT (M) 15°42'22''N 119°53'45''E
TALAMPULAN I (DS) 12°07'55''N 119°50'31''E
TARUMPITAO PT (M) 09°02'58''N 117°37'44''E
PANAY I (M) 13°58'41''N 124°18'48''E
SAIPAN (M) 15°07'50''N 145°41'41''E
OROTE PT (DS) 13°26'N 144°37'E
YAP (DM) 09°32'36''N 138°09'07''E
ANGUAR (S) 06°54'59''N 134°09'02''E
1L2
1L3
1L7
1L6
2H5
2H4
2H3
2H2
2H1
2L5
2L6
2L7
1L0
1L1
2S1
2S2
2S3
2S4
2S5
2S6
2S7
2S0
2H7
2H6
2H5
2H4
2H3
1L6
1L7
2L1
2L2
2L3
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
70°
60°
50°
40°
30°
20°
10°
0°
10°

BASIC PRR	SPECIFIC PULSE RECURRENCE RATE		PULSE RECURRENCE TIME (μs)
	STATION NUMBER	PULSES PER SECOND	
Slow (S) 20 pps	0	20	50,000
	1	20.04	49,900
	2	20.08	49,800
	3	20.12	49,700
	4	20.16	49,600
	5	20.20	49,500
	6	20.24	49,400
	7	20.28	49,300
Low (L) 25 pps	0	25	40,000
	1	25.06	39,900
	2	25.12	39,800
	3	25.19	39,700
	4	25.25	39,600
	5	25.31	39,500
	6	25.37	39,400
	7	25.44	39,300
High (H) 33⅓ pps	0	33.33	30,000
	1	33.44	29,900
	2	33.55	29,800
	3	33.66	29,700
	4	33.77	29,600
	5	33.88	29,500
	6	34.00	29,400
	7	34.11	29,300

Figure 21-4. Loran-A Pulse Recurrence Rates Table

- The station has a specific PRR of 33.44 pulses per second.
- At any point on the hyperbola, the time difference value is 1700 μs for that station.

Ground Waves and Sky Waves

The path over which loran signals travel affects their range, their characteristics, and the reliability of their time difference readings. As explained in Chapter 9, radio energy which travels along the surface of the earth is called the *ground wave,* and that which is reflected from the ionosphere is called the *sky wave.* The sky wave is named after the atmospheric layer that reflects it and the number of hops (bounces) it takes. See figure 21-5 for examples of sky waves and ground waves.

A loran pulse which travels to the ionosphere and back travels a greater distance than one which follows the surface of the earth. The additional distance it travels depends on the height of the reflecting layer, the number of hops it takes, and the distance of the receiver from the transmitter. Because of these variables, sky wave time difference readings are not as accurate as ground wave readings. For this reason, ground waves should be used when available even though they may be considerably weaker than sky waves. When a loran receiver is within 250 miles of a loran transmitter, sky waves produce an unacceptable error in time difference readings.

When ground waves are not available, one-hop-E sky waves can be used to obtain LOPs with reasonable accuracy. But when two-hop-E sky

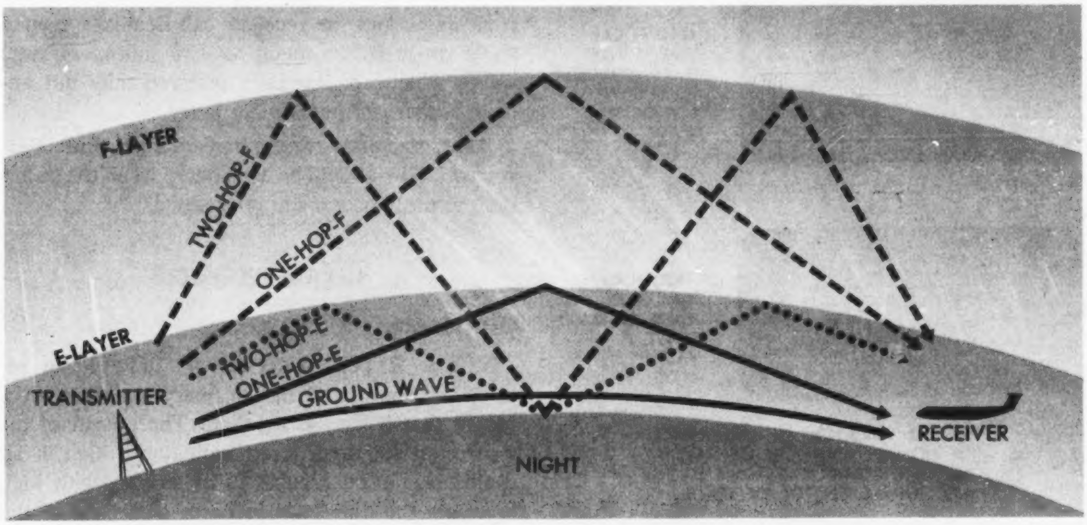
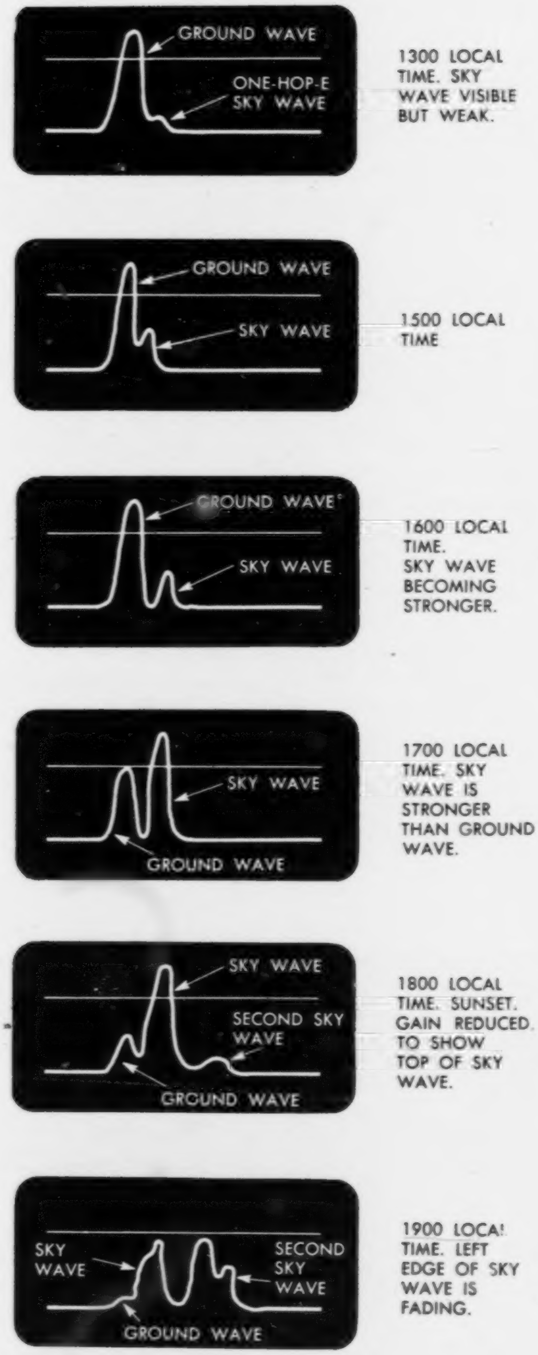


Figure 21-5. Both Ground Waves and Sky Waves may be Received

◄ Figure 21-3. Pacific Area Loran-A Coverage


GROUND WAVE
ONE-HOP-E SKY WAVE
1300 LOCAL TIME. SKY WAVE VISIBLE BUT WEAK.
GROUND WAVE
SKY WAVE
1500 LOCAL TIME
GROUND WAVE
SKY WAVE
1600 LOCAL TIME. SKY WAVE BECOMING STRONGER.
SKY WAVE
GROUND WAVE
1700 LOCAL TIME. SKY WAVE IS STRONGER THAN GROUND WAVE.
SKY WAVE
SECOND SKY WAVE
GROUND WAVE
1800 LOCAL TIME. SUNSET. GAIN REDUCED TO SHOW TOP OF SKY WAVE.
SKY WAVE
SECOND SKY WAVE
GROUND WAVE
1900 LOCAL TIME. LEFT EDGE OF SKY WAVE IS FADING.

TYPICAL VARIATION IN APPEARANCE OF SIGNALS WITH TIME OF DAY. BALANCE CONTROL IS ADJUSTED FOR NO SIGNALS ON TOP OF TRACE.

Figure 21-6. Variation of Sky Waves with Time of Day

waves are used, the error is multiplied to the point where the time difference readings produce unusable LOPs. The F-layer of the ionosphere is too unstable to provide reliable time difference readings.

Factors Affecting Loran Signals

DISTANCE FROM EACH TRANSMITTER. The distance of the master and slave transmitters from the aircraft is one factor which affects loran signals. It is possible to receive a ground wave from one transmitter and a sky wave from the other. For example, when the ground wave from the slave transmitter is beyond the range of the aircraft receiver, the first pulse in the slave pulse train will be a sky wave, not a ground wave. A *pulse train* is the order in which the pulses appear on the trace.

TIME OF DAY AT EACH TRANSMITTER. Sky waves are normally received at night, but they are also received occasionally during daylight hours. It is not unusual for the first reflection of sky waves to occur in the late afternoon before sunset, and to continue into morning daylight for three or four hours. This is especially true when the transmitter is in an area which is still dark. Figure 21-6 illustrates the variation of sky waves with the time of day.

INTERVENING LAND MASSES. When a ground wave passes over land, its range is significantly reduced because of the attenuation properties of land. As little as 30 miles of land between the transmitter and the receiver can decrease ground wave range by as much as 150 miles. Ground waves which are normally received may not appear because of intervening land.

These factors—range, time of day, and intervening land—should be considered when the pulses on a loran indicator are interpreted.

LORAN RECEPTION

Components

LORAN RECEIVER-INDICATOR. The loran receiver is similar to the ordinary radio receiver except that it has no speaker. The output of the receiver is fed to a loran indicator, which is an electronic device capable of measuring with high precision the difference in times of arrival of the pulse signals from the master and slave station.

Within the cathode ray tube of the indicator, a beam of electrons is directed against the inside of the indicator face. At the point of impact, the electron stream produces a spot of light. The electron stream is deflected at extremely high speed, causing the spot to "paint" a line of light which can be seen on the outer face of the indicator. This line is divided into an upper trace and a lower trace, one above the other. On some indicators, a faint line called a retrace can be seen connecting the ends of the two traces. This reveals the path of the spot in moving from the end of one trace to the beginning of the next.

When the controls are set to receive a given station, the length of the combined trace, in microseconds, is adjusted to the time interval between the beginning of each pulse (PRT). Thus, if a reading is desired on station 2H5, separate switches are set on 2, H, and 5 to control the frequency, basic PRR, and specific PRR, respectively. The combined length of the two traces is then 29,500 μs (from the table shown in figure 21-4).

When the controls are thus set for a given station, the signals of that rate appear as vertical pulses which remain stationary. Pulses of the same basic PRR, but of a different specific PRR, appear to drift along the trace. Those of a lower rate drift to the right and those of a higher rate drift to the left. The greater the difference in specific PRRs, the faster the rate of drift.

The master and slave signals can be identified by their relative positions on the sweep. The total time from the master pulse to the slave pulse is always greater than one half the repetition period. Therefore, if the master signal appears near the left of the top trace, the slave signal appears on the bottom trace and to the right of the master signal. Since the indicator may be turned on during any part of the cycle, the slave signal may appear on the top trace and the master on the bottom. These positions can be reversed by manipulating a switch which temporarily changes the sweep recurrence rate and causes the signals to move left or right. In this manner, the master and slave pulses can be positioned so that they can be readily identified. When a signal drifts past the end of a trace, it jumps to the opposite end of the other trace.

Details of measuring the time difference vary with the type of indicator.

ANTENNA SYSTEMS. All loran systems include an *antenna* and a *coupler*. After the signal is received by the antenna, it passes through the coupler. In some installations, an electronic antenna is part of the coupler. The coupler may pass the signal directly to the set or it may amplify a weak signal before passing it on. In all cases, it acts as a filter. The degree of amplification depends on the setting of the *local-distant switch* on the receiver. If no such switch is installed, the coupler always amplifies the signal. When a signal from a near-by transmitter is being received, the local position should be selected because the amplification of already strong signals distorts the pulses on the indicator.

Controls

The *channel selector* tunes the set to the frequency of the station. The PRR selector sets in the basic PRR of the station, and the *station rate selector* varies the basic PRR to the specific PRR desired. The drifting of the station pulses along the traces is stopped by the drift control, which refines the specific PRR. The pulses can be manually positioned by use of a *left-right switch*. The *function selector* enables the operator to expand certain small sections of the sweep to cover the entire indicator face. This permits greater accuracy in the matching of pulses.

The last control to be used is generally the *delay control*, which allows the time difference to be measured. This time difference, in microseconds, is presented on the indicator or on dials on the receiver.

LORAN FIXING AND PLOTTING

Identification of Loran Signals

Identification of both ground waves and sky waves is essential for the correct interpretation of loran readings. Pulses appear on the indicator in the order in which they are received, beginning at the left as illustrated in figure 21-7. Since the ground wave path is shortest, a ground wave pulse appears first, followed by the one-hop-E pulse. The other sky waves then appear in the ascending order of the distance traveled.

A critical zone exists at the outer limits of ground wave range. When signals are received within this zone, the navigator cannot be sure whether the first pulse on the indicator is the

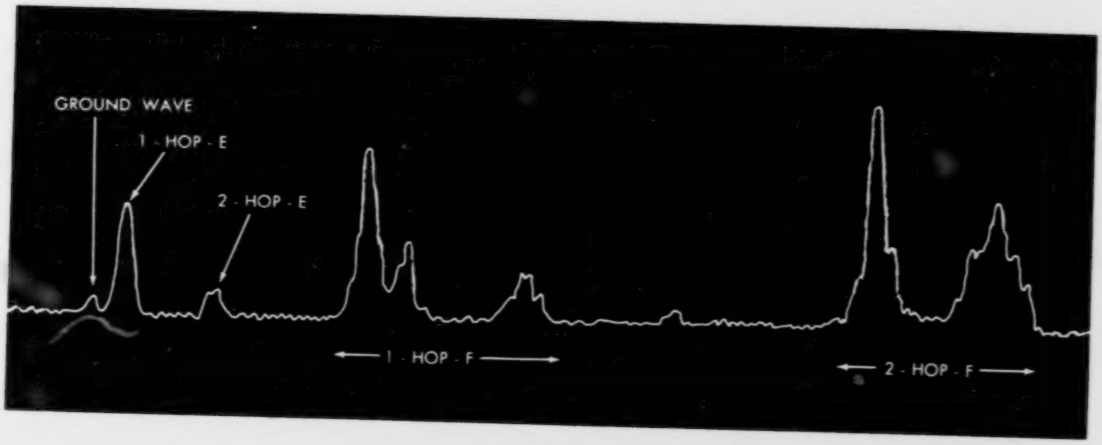


Figure 21-7. Identification of Loran Pulses

ground wave or the one-hop-E sky wave. This critical zone varies with time of day, geographic region (over land or water), and ionospheric conditions. In general, it occurs at ranges of approximately 600 to 900 miles by day, decreasing to approximately 400 to 700 miles at night.

The appearance of the waves helps in their identification. Normally, the strength of a ground wave pulse changes slowly. In contrast, the strength of a sky wave pulse changes rapidly. Sky waves sometimes appear as steady as ground waves, but such steadiness seldom lasts for more than a few minutes.

Changes in the strength of loran signal arriving at the receiver is called *fading*. The fading cycle may last less than a minute, or it may extend over a period of several minutes.

Sky waves are also subject to splitting. This is a division into two or more peaks which may fade independently. The first part of a sky wave may completely fade away, and a reading taken on the remaining portion would be in error. The typical splitting and fading of a sky wave is illustrated in figure 21-8. Again, a few minutes' study of the scope is the best precaution. During this study, it is well to turn up the receiver gain to the maximum consistent with the noise level, so that comparatively weak signals or leading portions of signals are not overlooked.

When matching two splitting sky waves, the left edges of the two pulses may differ with respect to height and slope. Experience has proved that, when this situation exists and the navigator is reasonably assured that the sky wave is not in

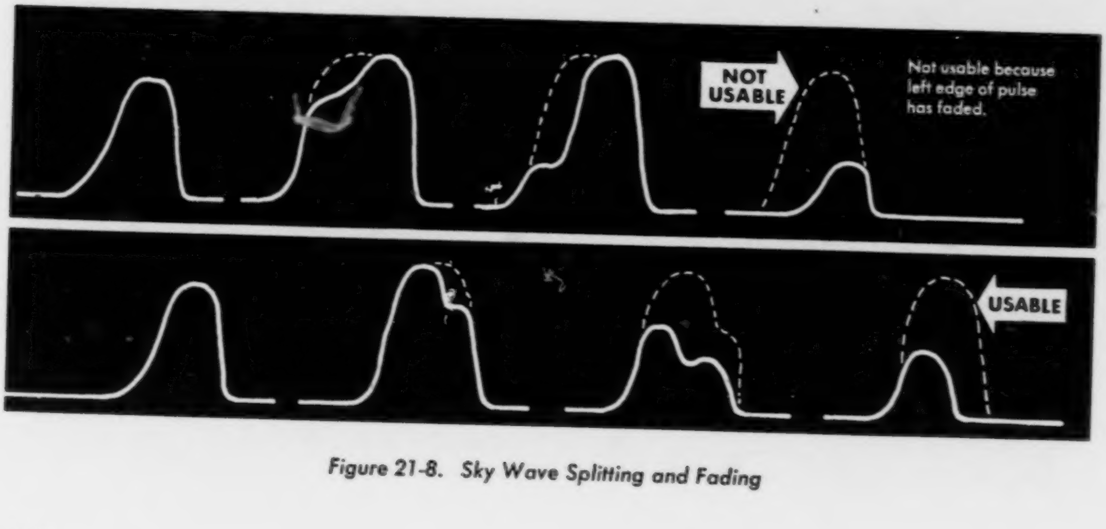


Figure 21-8. Sky Wave Splitting and Fading

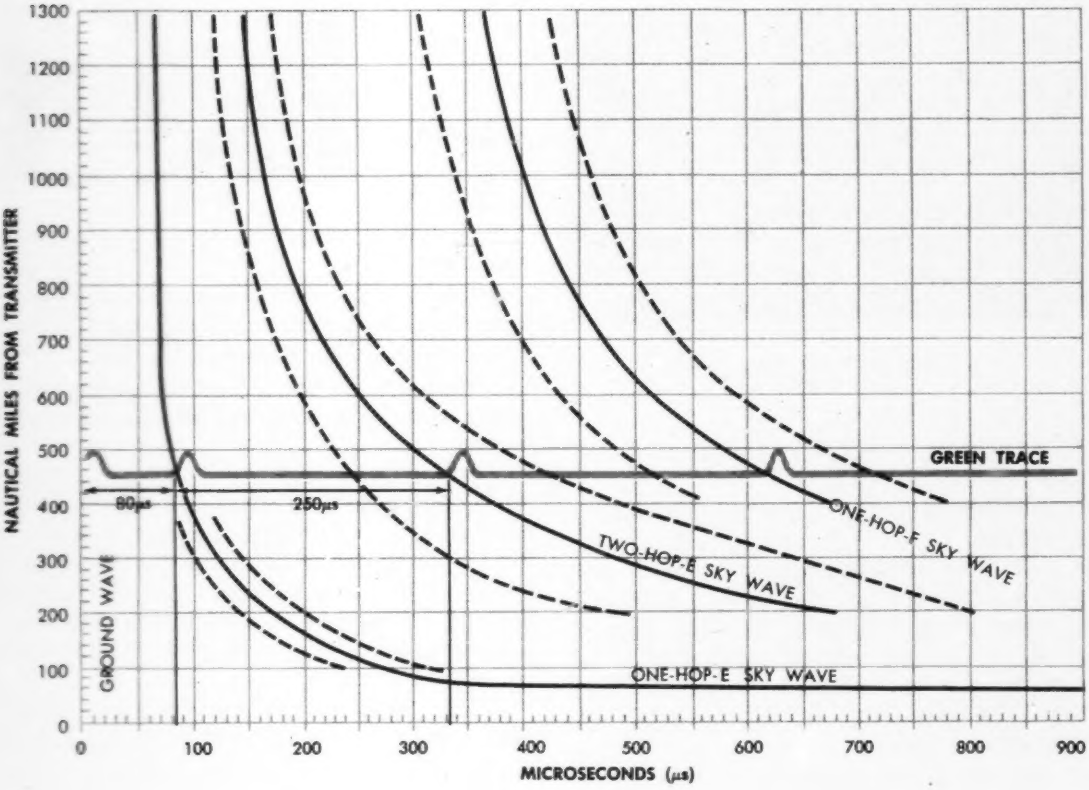


Figure 21-9. Pulse Position Graph

the process of splitting and fading, a match of the lower left-hand edges gives the most accurate readings.

PULSE POSITION GRAPH. The pulse position graph, figure 21-9, may be used to identify the pulses which are seen on the scope when more than one signal from a loran station (master or slave) is being received. On this graph, the horizontal lines represent nautical miles from the transmitter to the receiver; the vertical lines represent microseconds along the trace. The curved, solid, black lines represent the usual time difference between a ground wave and a one-hop-E sky wave, a one-hop-E and a two-hop-E sky wave, and between a two-hop-E and a one-hop-F sky wave. The dashed lines on either side of the solid lines represent maximum deviations from the usual time differences which may occur because of variations in the ionosphere. The ground wave is represented by the left edge of the graph. A horizontal line, which shows the usual presentation of loran pulses on a loran receiver 460 NM from the respective transmitter, is superimposed on this graph. At 460 NM from the transmitter, the difference from the left edge of the ground wave to the left edge of the one-hop-E sky wave is 80 μs; the difference between the one-hop-E and the two-hop-E sky waves is 250 μs.

Identifying Sky Waves. By comparing the microsecond value obtained between the left edges of two doubtful pulses to the usual spacing of these pulses, the proper identity of the signals may be found.

The following example explains the procedure: The navigator wants to identify the two pulses *A* and *B* on the top trace, shown in figure 21-10. The receiver is approximately 460 nautical miles from the transmitter of pulses *A* and *B*, and approximately 900 nautical miles from the transmitter of the bottom pulses. To identify pulse *A* and pulse *B*:

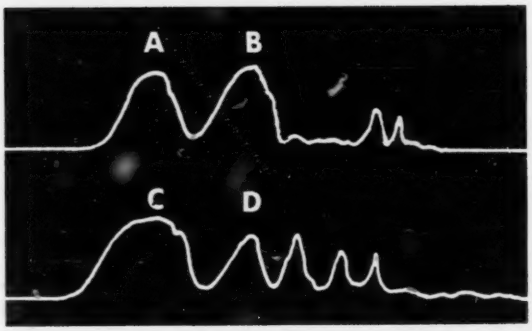


Figure 21-10. Identifying Pulses

1. Align pulse *A* with *C* and note the reading (3690 μs).
2. Align pulse *B* with *C* and note the reading (3940 μs).
3. The time difference between pulse *A* and pulse *B* is 250 microseconds (3940 μs - 3690 μs).
4. Enter along the left of the pulse position graph (figure 21-9) with 460 nautical miles and note that the time difference between the one-hop-E sky wave curve and the two-hop-E sky wave curve is 250 μs.
5. Therefore, pulse *A* is a one-hop-E pulse, and pulse *B* is a two-hop-E.

The left edge of the graph corresponds to a ground wave. If the difference between *A* and *B* were 80 μs, the graph would identify pulse *A* as a ground wave and pulse *B* as a one-hop-E sky wave. A good rule to follow: *A difference of 100 μs or more between the first two pulses is a positive indication that only sky waves are present.*

To identify pulses *C* and *D* in figure 21-10, match pulses *C* and *D* with pulse *A*, as in the previous example.

Sky Wave to Ground Wave Correction. In an area where a ground wave from one transmitter and a one-hop-E sky wave from the other transmitter of a station are being received, use the pulse position graph to match the sky wave with the ground wave. Determine from which transmitter (master or slave) the sky wave is received, and determine the approximate distance from that transmitter.

Enter the graph (figure 21-9) with the distance from the one-hop-E sky wave transmitter and intercept the one-hop-E sky wave curve; proceed straight down and read the correction on the bottom scale of the graph. Apply the correction as follows:

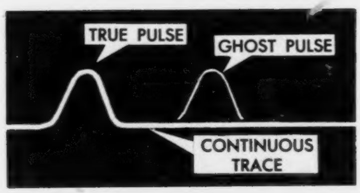


Figure 21-11. Ghost Pulse

1. When the sky wave is from the slave transmitter, subtract the correction from the time difference reading: Sky Slave Subtract (SSS).
2. When the sky wave is from the master transmitter, add the correction to the time difference reading.

Example: An aircraft receives a one-hop-E sky wave from a slave transmitter which is 400 nautical miles away, and receives a ground wave from the master transmitter. For that distance, a correction of 90 μs is extracted from figure 21-9 and subtracted (SSS) from the time difference reading to obtain the correct time difference.

INTERFERENCE.

Static. Static has the appearance of "grass" on the traces. Grass appears on the scope as a multitude of vertical lines. the number and size of which depend on the amount of interference. Lightning or heavy precipitation may temporarily obscure loran signals by creating heavy grass or by completely eliminating the signal. Readings may be made between disturbances. Radar interference produces a series of pips resembling loran signals, but they are equally spaced across the traces.

Spillover. When a receiver is near one loran station, and tuned to a station pair of different frequency, a spillover may occur; that is, weak signals from the nearby station may appear. If spillover is suspected, shift to the frequency of the nearby station. A spillover signal then becomes stronger, while the signal of the other frequency disappears or becomes relatively weaker.

Ghost Pulses. A faint signal image may be visible on the scope caused by ghost pulses from a station having a basic recurrence rate different from the rate to which the receiver is set. These pulses can be identified by the fact that they are weaker and appear at intervals of about 10,000 μs. Generally the signal flickers and may drift at a faster rate than the others. If the signal is amplified, the trace will be continuous below the ghost pulse as shown in figure 21-11.

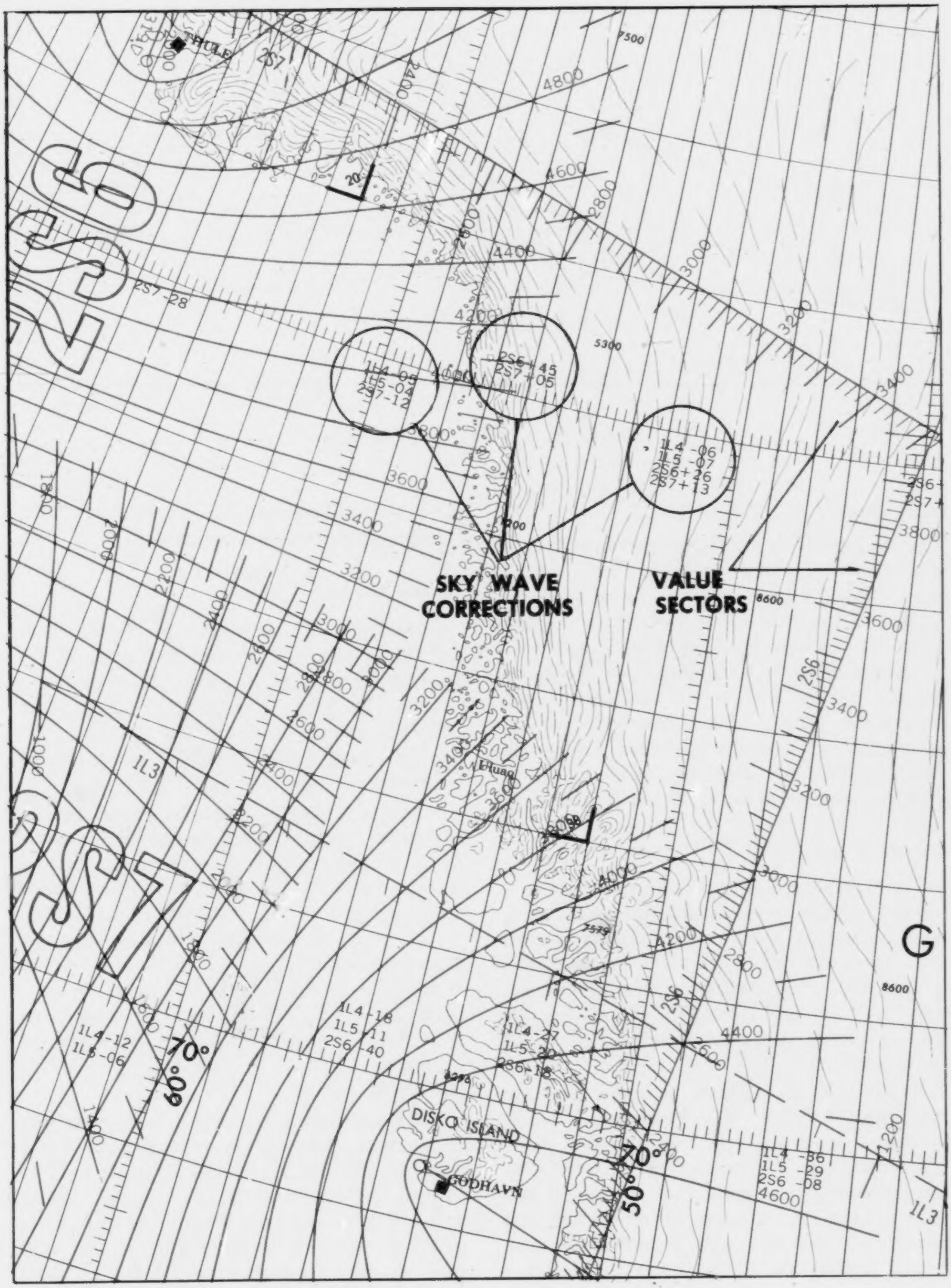

THULE
2S7
2S6
2S7
7500
4800
4600
2800
4400
3000
3200
3400
2S7-28
1L4-05
1L5-04
2S7-12
2S6+45
2S7+05
5300
1L4 -06
1L5 -07
2S6+26
2S7+13
SKY WAVE CORRECTIONS
VALUE SECTORS
8600
3800
3600
1L3
G
1L4-12
1L5-06
1L4-18
1L5-11
2S6-40
1L4-27
1L5-20
2S6-18
70°
60°
DISKO ISLAND
GODHAVN
70°
50°
1L4 -36
1L5 -29
2S6 -08
4600
1L3

Figure 21-12. Sky Wave Corrections on Loran-A Chart

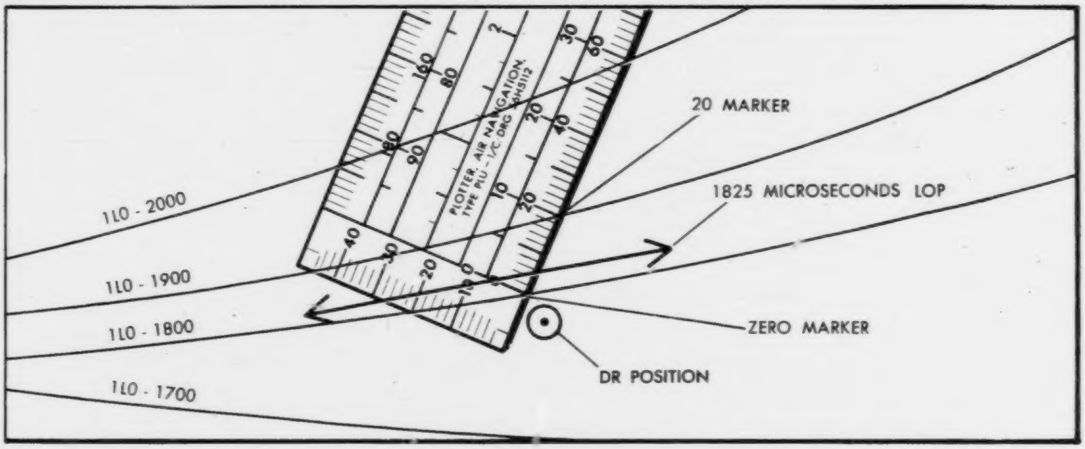


Figure 21-13. Interpolation Using Plotter

Loran Charts

Loran hyperbolas are normally printed 100 μs apart on loran charts. (Figure 21-12 is a section of a LORAN-A chart.) To determine the exact position of a given LOP, it is necessary to interpolate between the printed LOP. Additional LOPs are printed 20 or 50 μs apart when the distance between 100 μs LOPs is too great for accurate interpolation. To minimize clutter on some charts, value sectors are printed when hyperbolas become nearly straight lines. Value sectors are graduated scales between which the LOPs are plotted.

Sky Wave Correction

The hyperbolas drawn on loran charts are constructed specifically for ground waves; therefore, sky wave readings must be corrected before plotting. This correction, called *sky wave correction,* is used only when comparing a one-hop-E sky wave with another one-hop-E sky wave. Sky wave corrections are printed on the loran chart illustrated in figure 21-12.

As the loran transmitters are approached, the magnitude of the sky wave correction increases because a greater difference in travel time exists between the ground wave and the sky wave. Sky wave corrections are positive on the master side of the center line, zero on the center line, and negative on the slave side of the center line. Before plotting the LOP, apply the sky wave correction applicable to the specific geographical location to the final reading from the set. If the receiver is located between the sets of printed corrections, interpolation is necessary.

Plotting the LOP

In most cases, a time difference reading does not fall exactly on a printed hyperbola of the chart. To plot the LOP, interpolate between two printed hyperbolas on either side of the time difference reading near the DR position. The LOP is then drawn parallel to the charted hyperbolas.

PLOTTER METHOD. There are several ways to interpolate between printed hyperbolas. In figure 21-13, a reading of 1825 μs has been obtained from station 1L0. To plot this LOP, subdivide the space between the 1L0-1800 and 1L0-1900 hyperbolas into increments by using the edge of a plotter and the graduations marked on it. Notice in figure 21-13 that, by placing the plotter diagonally across the 1800 and 1900 hyperbolas, the space is subdivided into a convenient number of increments, usually 10. The 1825 μs LOP is then easily located.

DR COMPUTER SLIDE METHOD. Another way to interpolate between hyperbolas involves the use of the DR computer slide. Span the distance between the hyperbolas (in this example 100 μs) with a pair of dividers. Then place the divider points on the DR computer slide so that they span 10 drift lines, as shown in figure 21-14. Each drift line then represents 10 μs. Adjust the dividers to measure the value being inter-

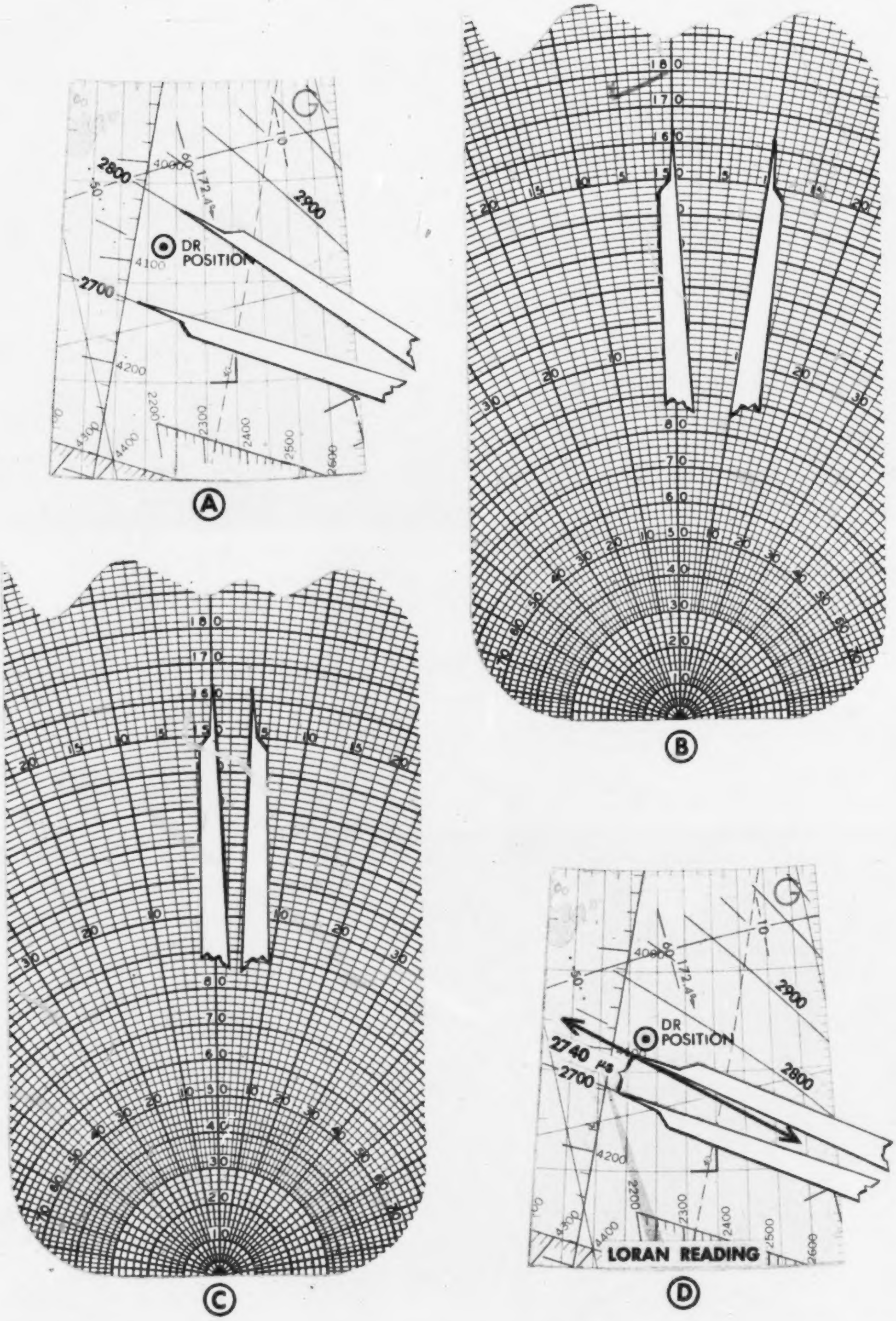
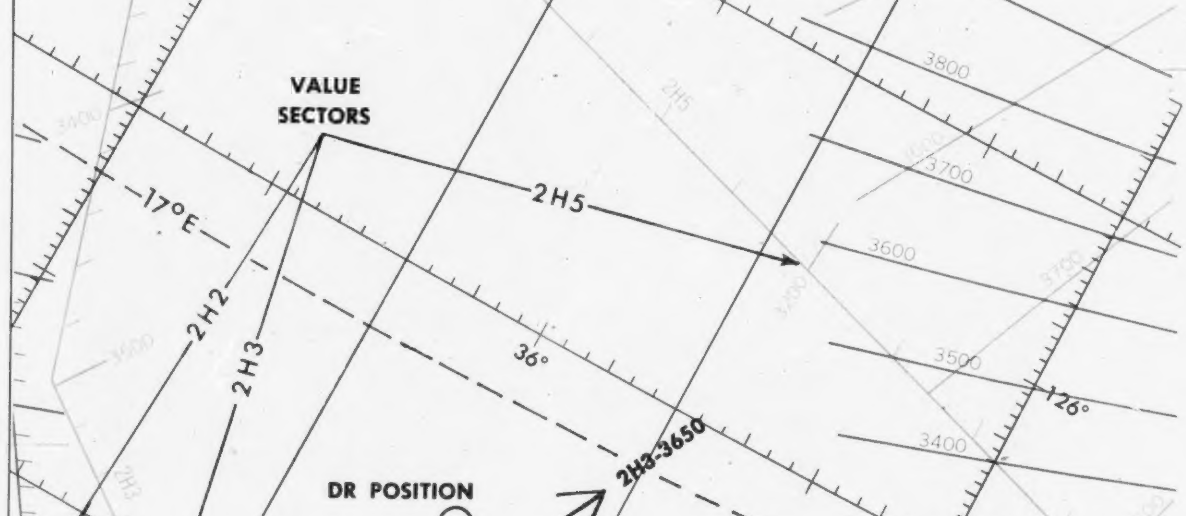
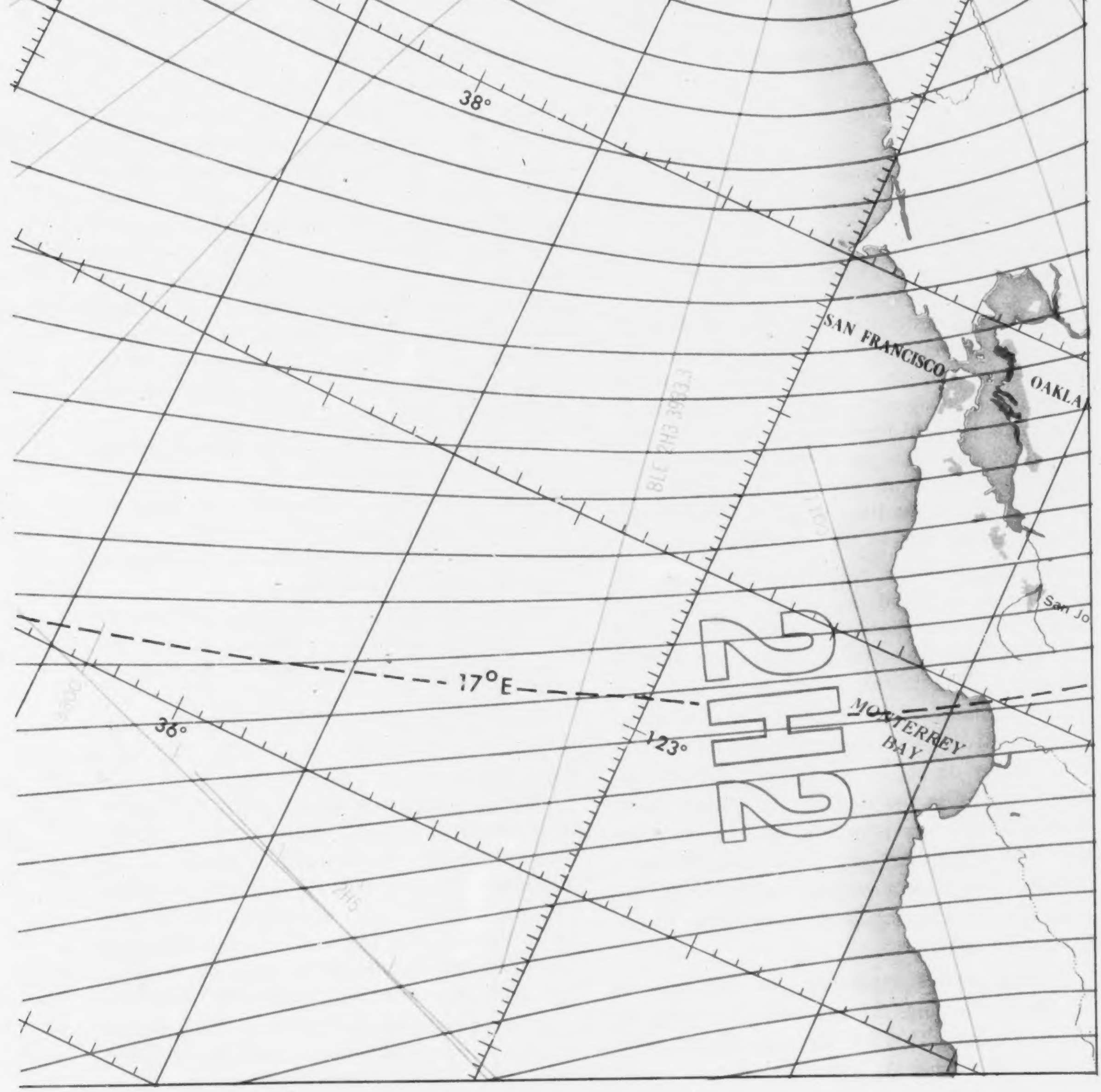

A
2800
2900
2700
DR POSITION
4000
4100
4200
4300
4400
172.4°
2200
2300
2400
2500
2600
B
C
D
2740 μs
LORAN READING

Figure 21-14. Interpolation Using Dividers and Computer Slide



38°
4100
3600
4000
3900
3800
3300
129°
VALUE
SECTORS
2H5
3400
3700
17°E
3600
2H2
2H3
3500
36°
126°
2H3-3650
DR POSITION
1330
2H2-3200
3300
3200
3100
3000
2900
2800
2700
2600
34°
2800
126°

Figure 21-15. A Loran Fix


126°
18°E
2H2 AND 2H3
MASTER TRANSMITTER
38°
SAN FRANCISCO
OAKLA
San Jo
2H2
MONTERREY
BAY
17°E
36°
123°

polated (40 μs), and with the dividers, plot this distance on the chart from the hyperbola of lower value towards to hyperbola of higher value.

NOTE: The interpolated distance must be plotted on the chart at the same place the original distance was spanned.

PROPORTIONAL FORMULA METHOD. A proportion also can be used to determine the proper spacing for the interpolated LOP. Using the previous example, assume that the distance perpendicular to the LOPs from the 2700 hyperbola to the 2800 hyperbola is 62 NM. Set the following proportion on the DR computer:

$$\frac{62\text{NM}}{100\ \mu\text{s}} = \frac{X}{40\ \mu\text{s}}$$

$$X = 25\ \text{NM}$$

The 2740 LOP is located 25 miles toward the 2800 hyperbola from the 2700 hyperbola on the chart.

Homing

To home a destination by use of loran, select the hyperbola which is plotted through destination and passes near the aircraft present position. If destination does not lie on a printed hyperbola, interpolate between hyperbolas to obtain the correct time difference value for destination. All applicable corrections, sky wave and others, depending on the receiver, must be applied with their signs reversed to the hyperbola value.

When the correct time difference value has been determined and preset into the loran receiver, the aircraft heading is altered to intercept it. The direction to turn depends on the aircraft location relative to the desired hyperbola. The aircraft location relative to the desired hyperbola is determined by the positions of the master and slave pulses on the loran indicator. When the slave pulse is to the right of the master pulse, the aircraft is on a hyperbola of a higher value than that which has been preset into the loran receiver. When the slave pulse is to the left, the aircraft is on a hyperbola of lesser value. Rule: *Slave Left,* value *Less.*

As the aircraft approaches the hyperbola to be used in homing, the two pulses move closer to one another. They are vertically aligned when the aircraft reaches the hyperbola. A turn is then made to fly down the hyperbola toward destination.

Accuracy

The accuracy of individual lines of position depends on the following factors.

SYNCHRONIZATION OF SIGNALS. Transmission of loran signals is continuously monitored. Normally, the timing is correct to a fraction of 1 μs, but if the signals get out of synchronization by as much as 2 μs, the master pulse, the slave pulse, or both, blink to warn the user of the situation. Blinking is the shifting of pulses right and left about 1,000 μs, at intervals of two seconds. When blinking is seen, readings from the station should be avoided until the synchronization is restored, usually in a few minutes.

POSITION RELATIVE TO THE TRANSMITTERS. Accuracy is related to the spacing between hyperbolas. Along the base line between the transmitters, where the hyperbolas are closely spaced, an error of 1 μs in the reading produces a maximum error of 492 feet. Near the base line extensions, an error of 1 μs in the reading produces an error of *several miles* in the position. Any groundwave reading within 25 μs of the base line extension value or any sky wave reading within 200 μs of the base line extension value should be considered of doubtful accuracy.

At distances of 800 miles or more, carefully obtained sky wave readings have an average error of about two microseconds. The error increases as the stations are approached, reaching an average value of about 7 μs at a distance of 250 miles from one of the transmitters.

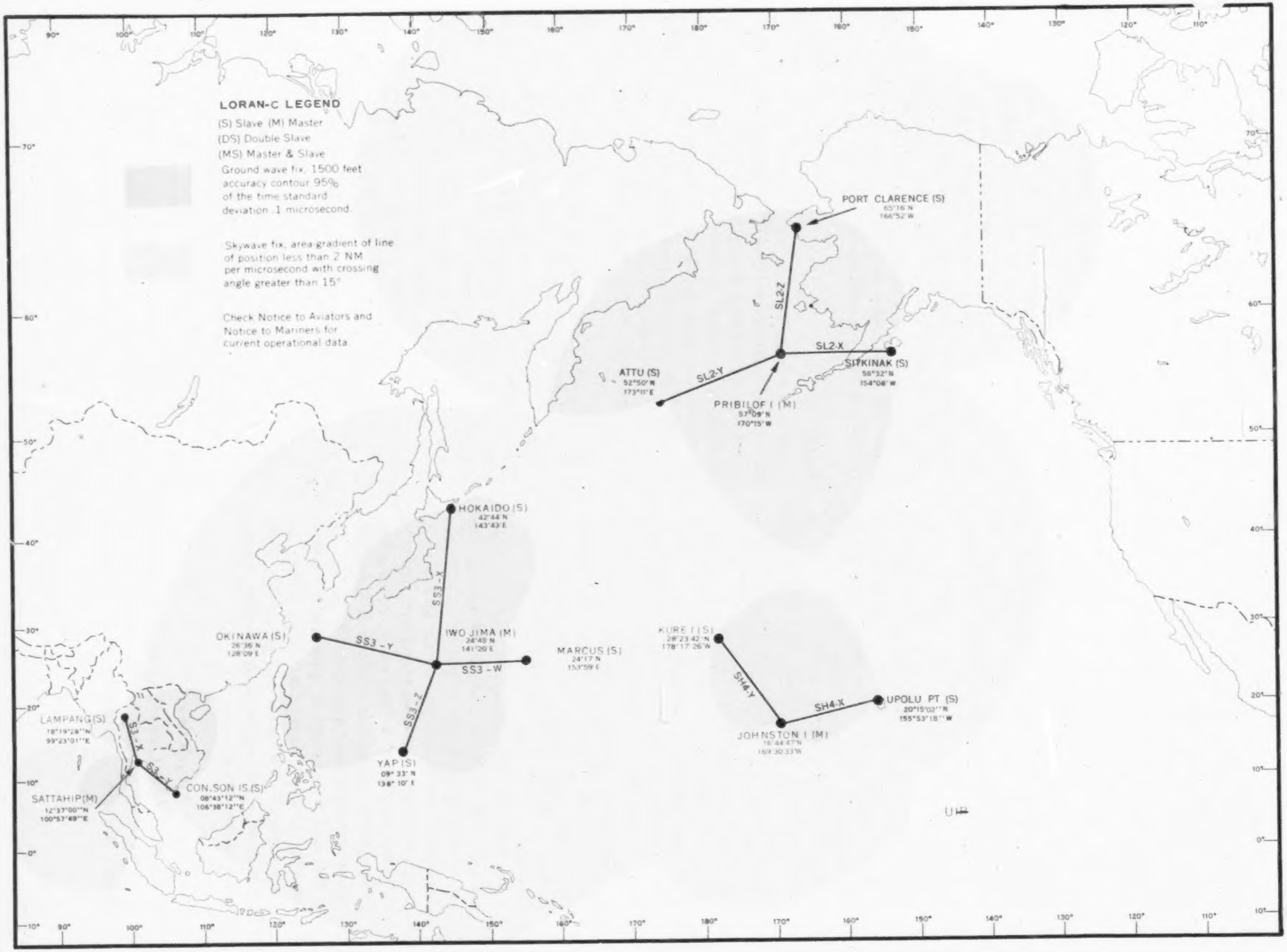
As in other forms of navigation, the accuracy of a loran fix depends on the accuracy of the individual lines of position, and on the angle at which they intersect.

Three LOPs provide the most accurate fix. When only two LOPs are available, 90° LOP cuts provide the most accurate fix.

The Loran-A chart in figure 21-15 shows a two LOP loran fix from stations 2H2 and 2H3. The LOPs were plotted using value sectors and hyperbolas. In this example, accurate interpolation was essential because the angle at which the LOPs intersect is less than 90°. A more accurate fix would have been obtained had the navigator been able to secure an LOP from station 2H5.

SKILL IN OBTAINING A READING. The principal source of error in obtaining a reading is in identifying the pulses. Patience and judgment are needed to avoid an error resulting from use of the

Figure 21-16. Pacific Area Loran-C Coverage ➤


LORAN-C LEGEND
(S) Slave (M) Master
(DS) Double Slave
(MS) Master & Slave
Ground wave fix, 1500 feet accuracy contour 95% of the time standard deviation .1 microsecond.
Skywave fix, area-gradient of line of position less than 2 NM per microsecond with crossing angle greater than 15°
Check Notice to Aviators and Notice to Mariners for current operational data.
PORT CLARENCE (S)
65°16'N
166°52'W
SL2-Z
SL2-X
SITKINAK (S)
56°32'N
154°08'W
ATTU (S)
52°50'N
173°11'E
SL2-Y
PRIBILOF I (M)
57°09'N
170°15'W
HOKAIDO (S)
42°44'N
143°43'E
SS3-X
IWO JIMA (M)
24°48'N
141°20'E
OKINAWA (S)
26°36'N
128°09'E
SS3-Y
SS3-W
MARCUS (S)
24°17'N
153°59'E
SS3-Z
YAP (S)
09°33'N
138°10'E
LAMPANG (S)
18°19'28''N
99°23'01''E
S3-X
S3-Y
SATTAHIP (M)
12°37'00''N
100°57'49''E
CON.SON IS.(S)
08°43'12''N
106°38'12''E
KURE I (S)
28°23'42''N
178°17'26''W
SH4-Y
SH4-X
JOHNSTON I (M)
16°44'47''N
169°30'33''W
UPOLU PT (S)
20°15'02''N
155°53'18''W
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
70°
60°
50°
40°
30°
20°
10°
0°
10°

wrong pulse or from failure to detect the true leading edge. With a reasonable signal-to-noise ratio, a careful navigator should be able to match pulses and read the indicator with an error not exceeding 1 μs. With patience, very weak pulses can be matched with an error of not more than a few μs.

LORAN-C

Loran-C is a sophisticated extension of the basic principles used in Loran-A. It affords greater range, accuracy, and convenience of operation.

Transmission

In contrast to the single pair of transmitters used for a Loran-A station, Loran-C uses a master and at least two slave transmitters. Figure 21-16 shows transmitter configurations of three Loran-C stations in the Pacific area.

In some areas, a slave transmitter may be used as a slave for more than one master transmitter. It is then known as a double slave transmitter. Some master transmitters also may be used as slaves for other master transmitters. These are known as master-slave transmitters.

Because Loran-C operates in the low frequency band between 90 and 110 kHz, it is less subject to attenuation, giving it greater range than Loran-A. This allows the base lines between transmitters to be longer, thereby reducing the number of stations required to provide complete coverage.

Loran-C uses pulse groups instead of a single pulse for measurement of time differences. The use of pulse groups not only increases average transmitting power, but permits the measurement of time differences with accuracies not attainable by Loran-A. Phased coding of the multi-pulsed groups permits station identification and discrimination between ground waves and sky waves.

The master transmitter of a particular Loran-C network transmits nine pulses in its group; the slaves transmit eight pulses to a group. The additional pulse in the master group provides identification of the station.

Transmission Irregularities

The accuracy of Loran-C transmissions depends upon the correct tuning or synchronizing of the signals. Loran-C transmitting stations use a "blink" code as a warning of transmission irregularities. Such irregularities could be:

- Station not transmitting.
- Incorrect phase coding.
- Incorrect number of pulses.
- Incorrect pulse spacing.
- Incorrect pulse shape.
- Observed time difference at monitor station outside specified limits.

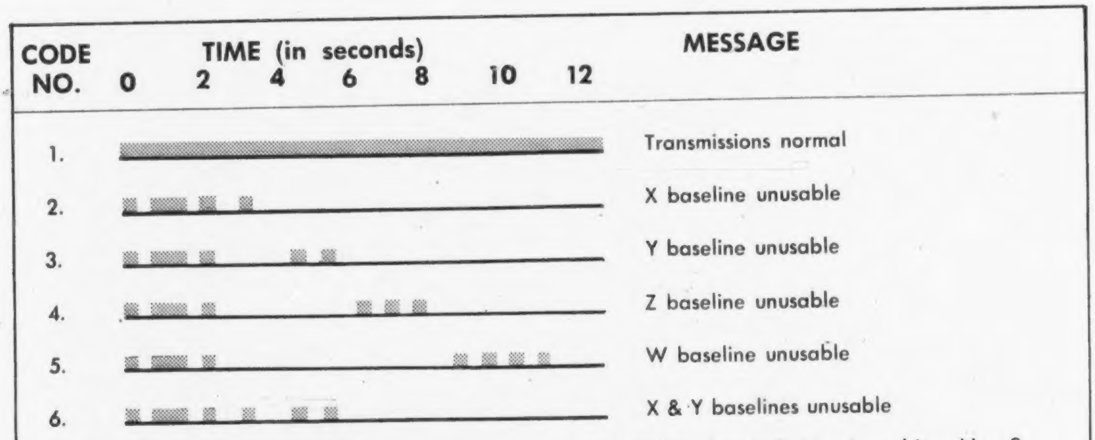
Both master and slave stations of a pair blink if either station is operating incorrectly; readings obtained from that pair must be treated wtih caution until both stations have stopped blinking. When a slave station blinks, the first two of the eight pulses are transmitted for only one-fourth second in every four seconds. The master station blinks the ninth pulse in a code, which is repeated in a twelve-second cycle (figure 21-17).

Reception

Loran-C ground wave coverage extends to approximately 1200 NM. Usable one-hop-E sky waves may be received during both daylight and darkness up to ranges of 2300 NM. Two-hop-E sky waves have been received from as far away as 3400 NM. However, almost complete darkness must be present between the transmitter and the aircraft receiver for stable two-hop-E sky wave use.

Some Loran-C recurrence rates are compatible with the Loran-A system, as shown in the table in figure 21-18. Loran-A receivers can be modified to permit reception of 100 kHz signals for pulse group matching of the signals in the conventional Loran-A manner. However, modified Loran-A receivers do not incorporate the capability of measuring "fine" time differences as Loran-C receivers do. As a result, less accuracy is obtained. The converted receivers also have the disadvantage of presenting only one reading at a time. This requires the navigator to advance or retard the LOPs.

Receivers specifically designed for Loran-C reception can be set for automatic operation. In this mode, they continuously and simultaneously track and display time difference readings for two Loran-C master-slave pairs operating on the same pulse recurrence rate. For example, SL2-X, SL2-Y and SL2-Z, shown in figure 21-16, operate on the same specific PRR. Advanced Loran-C receivers used with automatic navigational com-


CODE NO.
TIME (in seconds)
0
2
4
6
8
10
12
MESSAGE
1.
Transmissions normal
2.
X baseline unusable
3.
Y baseline unusable
4.
Z baseline unusable
5.
W baseline unusable
6.
X & Y baselines unusable

The blink codes shown above may appear in any combination; thus code No. 6 combines Nos. 2 and 3 and indicates that the X and Y baselines are unusable.

The remaining combinations of blink code signals are:

7. (Nos. 2 and 4)	X & Z baselines unusable
8. (Nos. 2 and 5)	X & W baselines unusable
9. (Nos. 3 and 4)	Y & Z baselines unusable
10. (Nos. 3 and 5)	Y & W baselines unusable
11. (Nos. 4 and 5)	Z & W baselines unusable
12. (Nos. 2, 3, & 4)	X, Y & Z baselines unusable
13. (Nos. 2, 3, & 5)	X, Y & W baselines unusable
14. (Nos. 2, 4, & 5)	X, Z & W baselines unusable
15. (Nos. 3, 4, & 5)	Y, Z & W baselines unusable
16. (Nos. 2, 3, 4, & 5)	X, Y, Z & W baselines unusable

Figure 21-17. Master Station 9th Pulse Blink Code

puters display this information as latitude and longitude.

Loran-C charts contain skywave corrections for day and night use (figure 21-19). These are printed at regular intervals on Loran-C charts in those parts of the coverage area where either two skywaves or a groundwave/skywave combination may be used. The following examples illustrate how these corrections are used:

- SH4-Y +01D

This indicates that where two skywaves are used for the master/slave pair SH4-Y, the daylight correction to be applied is plus 1YS.

- SH4-Y +02N

The nighttime correction for the example shown above is plus 2YS.

- SH4-X SG—39D

When using a master skywave and slave X groundwave, the correction is minus 39MS, during the day.

- SH4-X SG—56N

Same situation as above. The correction is minus 56MS, at night.

- SL2-Y GS+45D

Using master groundwave and Y slave skywave, the correction is plus 45MS, during the day.

If the receiver is located between the sets of printed corrections, interpolation is necessary.

BASIC PRR	SPECIFIC PULSE RECURRENCE RATE		PULSE RECURRENCE TIME (μs)
	STATION NUMBER	PULSES PER SECOND	
SS 10 pps	0	10.00	100,000
	1	10.01	99,900
	2	10.02	99,800
	3	10.03	99,700
	4	10.04	99,600
	5	10.05	99,500
	6	10.06	99,400
	7	10.07	99,300
SL 12½ pps	0	12.50	80,000
	1	12.52	79,900
	2	12.53	79,800
	3	12.55	79,700
	4	12.56	79,600
	5	12.58	79,500
	6	12.59	79,400
	7	12.61	79,300
SH 16⅔ pps	0	16.66	60,000
	1	16.69	59,900
	2	16.72	59,800
	3	16.75	59,700
	4	16.78	59,600
	5	16.80	59,500
	6	16.84	59,400
	7	16.86	59,300

BASIC PRR	SPECIFIC PULSE RECURRENCE RATE		PULSE RECURRENCE TIME (μs)
	STATION NUMBER	PULSES PER SECOND	
S 20 pps	0	20.00	50,000
	1	20.04	49,900
	2	20.08	49,800
	3	20.12	49,700
	4	20.16	49,600
	5	20.20	49,500
	6	20.24	49,400
	7	20.28	49,300
L 25 pps	0	25.00	40,000
	1	25.06	39,900
	2	25.12	39,800
	3	25.19	39,700
	4	25.25	39,600
	5	25.31	39,500
	6	25.37	39,400
	7	25.44	39,300
H 33⅓ pps	0	33.33	30,000
	1	33.44	29,900
	2	33.55	29,800
	3	33.66	29,700
	4	33.77	29,600
	5	33.88	29,500
	6	34.00	29,400
	7	34.11	29,300

Figure 21-18. Loran-C Pulse Recurrence Rates Table

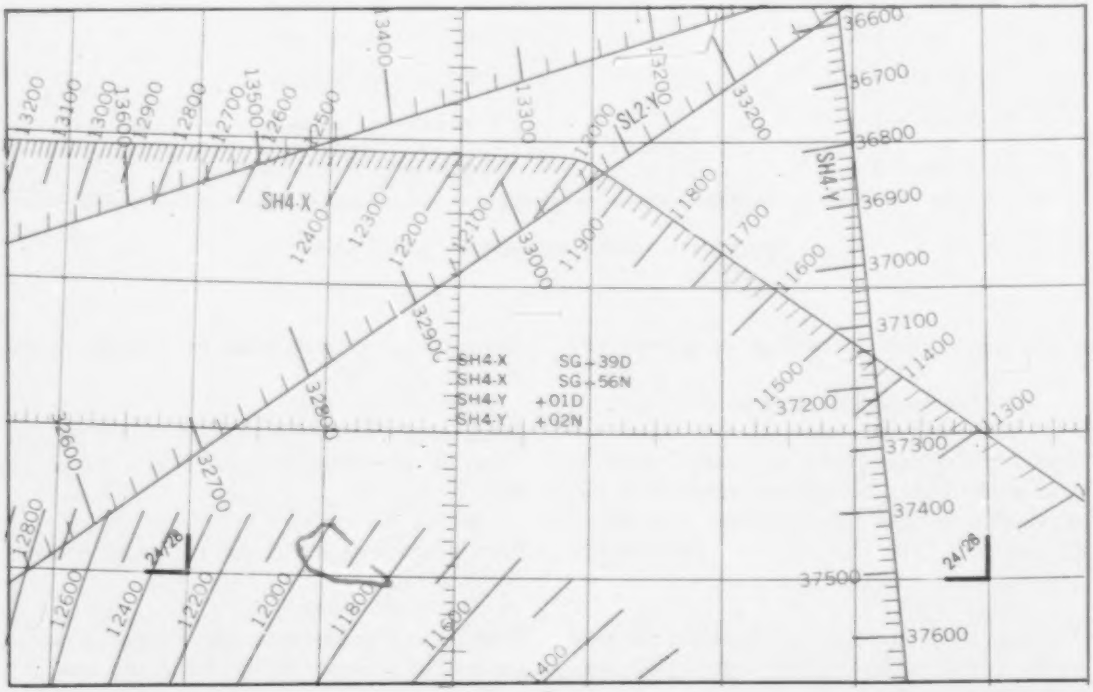

SH4-X
SL2-Y
SH4-Y
SH4-X SG+39D
SH4-X SG+56N
SH4-Y +01D
SH4-Y +02N
24/28
24/28
36600
36700
36800
36900
37000
37100
37200
37300
37400
37500
37600
13400
13300
13200
13100
13000
12900
12800
12700
12600
12500
12400
12300
12200
12100
12000
11900
11800
11700
11600
11500
11400
11300
33200
33000
32900
32800
32700

Figure 21-19. Day (D) and Night (N) Sky Wave Corrections on Loran-C Chart

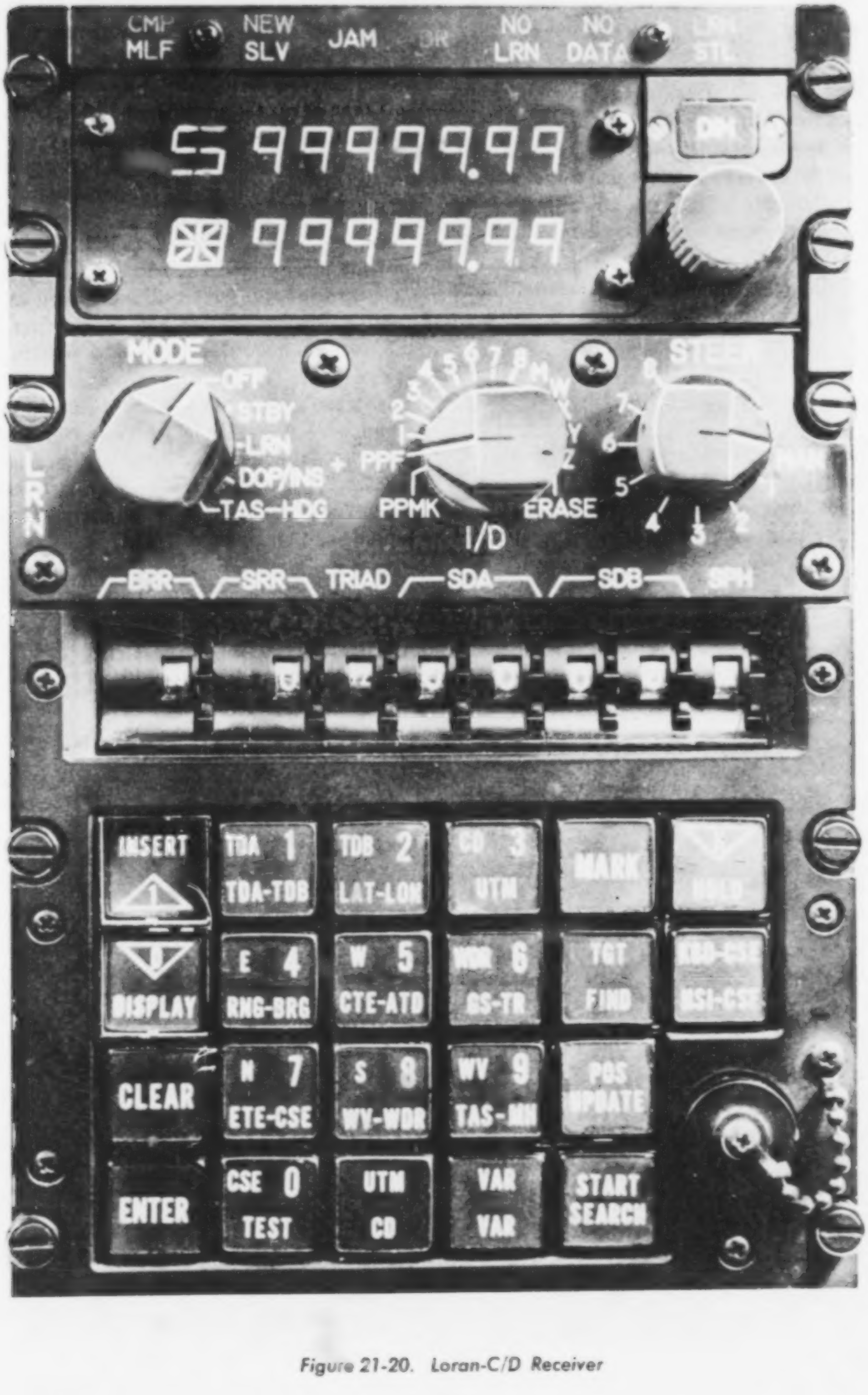

CMP MLF
NEW SLV
JAM
DR
NO LRN
NO DATA
LRN STL
DIM
MODE
OFF
STBY
LRN
DOP/INS
TAS-HDG
PPF
PPMK
I/D
ERASE
STEER
BRR
SRR
TRIAD
SDA
SDB
SPH
INSERT
TDA 1 TDA-TDB
TDB 2 LAT-LON
CD 3 UTM
MARK
HOLD
DISPLAY
E 4 RNG-BRG
W 5 CTE-ATD
WDR 6 GS-TR
TGT FIND
KBD-CSE HSI-CSE
CLEAR
N 7 ETE-CSE
S 8 WV-WDR
WV 9 TAS-MH
POS UPDATE
ENTER
CSE 0 TEST
UTM CD
VAR VAR
START SEARCH

Figure 21-20. Loran-C/D Receiver

Operation

The Loran-C receiver performs four basic functions:

1. It measures and tracks the carrier phase difference of two station pairs.
2. It measures and tracks the envelope time difference of the same two station pairs.
3. It continuously adjusts the amplitudes of the three pulse groups in order to present signals of constant amplitude to the error detectors.
4. It continuously monitors any combination of the three pulse groups for evidence of sky wave tracking.

LORAN-D

Loran-D is very similar in characteristics to its predecessor, Loran-C. The Loran-D system has relatively short range capability and is designed for tactical uses such as close air support and interdiction, reconnaissance, air drop, and rescue. A Loran-D transmitter may be transported to forward operating locations, and can be operational in short periods of time.

Loran-D operates in the 90-110 kHz band and has transmission characteristics very similar to Loran-C. The major difference between the two systems is that Loran-D transmits sixteen pulses per group as opposed to eight pulses per group transmitted by Loran-C. Loran-D is designed to provide precise navigation fixes (average predictable error of 600 feet) out to 250 nautical miles from the master station and usable fixes out to 500 nautical miles from the master station.

Combining Loran-C/D makes possible more precise navigation and position fixing for a variety of missions. Loran-C/D receivers (figure 21-20) provide continuous time difference measurements which, through the use of modern airborne computers, can provide readouts of aircraft position in latitude and longitude or UTM.

CHAPTER 22

Flight Information Publications and Air Traffic Control

An Air Force navigator must not only be thoroughly familiar with the techniques of aerial navigation, but he must also be familiar with other aspects of military flight operations. For example, he must be completely knowledgeable about (1) the directives and guidance provided in Air Force regulations and manuals pertaining to military flight operations; (2) Air Traffic Control systems existing throughout the world; and (3) the Flight Information Publications (FLIPs) which provide current data on Air Traffic Control and other data directive on all elements of the DOD. A brief discussion on these three subjects is contained in the following paragraphs.

AIR FORCE PUBLICATIONS

The Air Force uses many publications to give direction, offer guidance, explain policy, etc., to Air Force personnel. These publications include Air Force letters, manuals, pamphlets, regulations, and visual aids.

Among the publications which are of primary interest to Air Force navigators are the following:

- Flying Training—51 Series. These include such subjects as "Air Navigation," "Instrument Flying," etc.
- Operations—55 Series. These include such subjects as "Airfield Management and Base Operations," "NOTAMS," "Overdue Aircraft," etc.
- Flying—60 Series. All subjects in this series directly concern rated personnel. They include "General Flight Rules," "Air Traffic Control Procedures," etc.
- Flying Safety—62 Series. These include such subjects as "Reporting and Investigating Alleged Violations of Flying Regulations," etc.

Navigators should become thoroughly familiar with all flying publications provided by the Air Force. AFR 96-9 is of special interest to navigators. This regulation provides guidance on the submission of mapping, charting and geodetic (MC&G) product requirements and explains that the Defense Mapping Agency Aerospace Center (DMAAC) is available for technical assistance in defining cartographic requirements.

AIR TRAFFIC CONTROL SYSTEMS

General

Most nations of the world today have established airspace, air traffic units, and air traffic services to promote safe, orderly, and expeditious flow of traffic. Furthermore, many of the nations, in the interest of standardization, are establishing systems in accordance with the standards and recommended practices adopted by the International Civil Aviation Organization (ICAO). Air Force navigators must understand what these air traffic services are and how they can be used because military operations are directly affected by these services.

Air Traffic Service

Air traffic service is a general term used to mean any of the following services.

AIR TRAFFIC CONTROL. This is a service provided to aircraft by ground agencies to prevent collisions and to expedite and maintain an orderly flow of traffic. Air traffic control includes such services as area and enroute control, approach control, and tower control. It is used primarily under Instrument Flight Rules (IFR) conditions.

ADVISORY SERVICE. This is a service provided to give air information useful for the safe and efficient conduct of flight. This service is usually associated with Visual Flight Rule (VFR) conditions and includes such services as weather conditions, location of known traffic, status of navigation aids, status of aerodromes and facilities, etc.

ALERTING SERVICE. This is a service provided to notify appropriate organizations regarding aircraft in need of search and rescue aid and to assist such organizations as required.

Airspace

When it has been determined that air traffic services are to be provided, portions of the airspace are designated in relation to the air traffic services that are to be provided. Some of the more important divisions of the airspace follow.

CONTROLLED AIRSPACE. This is airspace of defined dimensions within which air traffic control service is provided.

AIRWAY. This is controlled airspace established in the form of a corridor equipped with radio navigation aids.

ADVISORY ROUTE. This is uncontrolled airspace similar to an airway along which air traffic advisory service is available. Advisory service provides separation or control from other *known* traffic.

CONTROL ZONE. This is controlled airspace extending upward from the surface of the earth. Normally these zones are circular areas surrounding one or more aerodromes.

FLIGHT INFORMATION REGIONS (FIR). This is an airspace of defined dimensions within which Advisory Service and Alerting Service are available. The FIR is the basic breakdown of the ICAO Regions (there are eight ICAO regions throughout the world). Also, portions of the FIR may contain controlled airspace. Some countries have established Upper Information Regions (UIR) for their High Altitude Airway Systems. When the UIR is implemented, it exists above the FIR.

POSITIVE CONTROL AREA (PCA). This includes all airspace in the United States, from 18,000 feet MSL to FL600. Only IFR flights are conducted in this area. All VFR activities, including climbs, descents, and VFR-On-Top operations on IFR flight plans are prohibited within a PCA. All aircraft operating within a PCA must have radio equipment capable of maintaining pilot-controller contact and have a coded transponder with a mode-3 code capability.

TERMINAL CONTROL AREA (TCA). This is the airspace designated in the vicinity of certain major terminal areas. All aircraft operating within a TCA are subject to Air Traffic Control.

Air Traffic Service Units

These are the units which provide the air traffic service within defined airspace.

AIR ROUTE TRAFFIC CONTROL CENTERS (ARTCC). This facility provides air traffic control to IFR flight within controlled airspace.

APPROACH CONTROL. This facility provides air traffic control to aircraft arriving at or departing from one or more aerodromes.

AERODROME CONTROL TOWER. This facility provides air traffic control service for aerodrome traffic.

FLIGHT SERVICE STATION (FSS). This facility is operated by the FAA to provide flight assistance service.

International Civil Aviation Organization (ICAO)

During the latter part of World War II, the United States Government, anticipating a large scale expansion of international air transport following the end of hostilities, determined that there was a need for an international convention to deal with certain aspects of civil aviation as they relate to international air transport operation. This led to the establishment of the International Civil Aviation Organization (ICAO) with headquarters in Montreal, Canada, in April 1947. ICAO is affiliated with the United Nations as a specialized international body dealing with aviation matters.

The member states (refer Section III, FLIP Planning) of the International Civil Aviation Organization subscribe to ICAO rules and procedures. These rules and procedures are used except for national deviations which are usually filed with ICAO. Since standardization in ICAO is built upon the same technical principles and policies which are in actual effect in the continental U.S., an American airman can fly all major routes following the same general rules of the air, using the same navigational equipment and communications practices and procedures, and being governed by the same traffic control services with which he is familiar at home.

Air Force policy is to support activities of the International Civil Aviation Organization (ICAO) in an attempt to standardize air facilities, services, procedures, and practices (see AFP 55-1-1, Air Force Participation in International Aviation). This standardization involves rules of the air, air traffic control, search and rescue, communications and navigational aids, maps and charts, flight information publications, meteorology, and aerodromes and visual aids. Nations may either adopt the ICAO standards, change them slightly, or not adopt them at all. What each nation does about ICAO standards constitutes that nation's rules of the air. Air Force crews must comply with the national rules of the foreign state being overflown. Therefore, when the provisions of AFM 60-16, General Flight Rules, conflict with the national rules of a foreign nation, the national rules apply. However, when the provisions of this regulation do not conflict with, but are more restrictive than the national rules, AFM 60-16 will apply. As a general policy, in international airspace over the high seas, Air Force operations are conducted in accordance with ICAO standards and recommended practices, military mission permitting.

NOTE: Deviations from ICAO standards and/or individual National Air Traffic peculiarities are listed in Enroute and Planning FLIPs.

U. S. military aircraft flying over a foreign country which is not a contracting state of ICAO must comply with the national practices of that country and any special provisions of the bilateral agreements the U.S. may have with that country. In the absence of any national practice or bilateral agreements governing rules of the air, the ICAO rules and procedures are followed.

Federal Aviation Administration (FAA)

The United States is a member of ICAO and follows ICAO standards. Deviations from ICAO standards are filed with ICAO. The Federal Aviation Administration (FAA) is responsible for air traffic services in the United States and its possessions in accordance with the Federal Aviation Act of 1958 which consolidated all air traffic regulatory agencies under the control of the FAA. Following are some of the responsibilities of the FAA.

- Operates the air traffic control system within the U.S. airspace.
- Establishes and assures compliance with the Federal Air Regulations (FARs) which are binding on the entire aviation community.
- Issues licenses to aircraft members, maintenance personnel, and control tower operators.
- Investigates aircraft accidents.
- Maintains communication stations and navigation aids.
- Flight checks navigation aids.

FLIGHT INFORMATION PUBLICATIONS

General

Complete aeronautical information concerning air traffic systems is published in the Flight Information Publications (FLIPs). The Department of Defense (DOD), in recognition of the importance of this information to military flight operations, has directed that FLIPs be published covering the entire free world area. The Defense Mapping Agency Aerospace Center (DMAAC), is responsible for the production and distribution of FLIP products to all members of the DOD.

FLIP Design

During the initial development of the FLIPs, all aeronautical information was carefully analyzed to determine the sequence and manner in which it would be used. This led to the establishment of categories of information based on primary operational use—i.e., Planning, Enroute, and Terminal—and the breakout of FLIP products accordingly. This means that a FLIP packet for any given area of the world consists of three basic components; a Planning FLIP, an Enroute FLIP, and a Terminal FLIP.

Areas of Coverage

There are eight DOD FLIP packets covering the free world area; the specific area of coverage of each packet follows:

1. U. S.
2. Alaska
3. Canada/North Atlantic
4. Caribbean/South America
5. Pacific/Southeast Asia
6. Australia/New Zealand/Antarctica
7. Europe/North Africa
8. Africa/Southwest Asia

FLIP Products General

As indicated previously FLIP products are separated into three categories of operational use. Following are the FLIP products associated with each category. These are discussed in more detail in subsequent paragraphs.

1. Planning: FLIP Planning documents, FLIP Planning Charts, and Foreign Clearance Guide.
2. Enroute: FLIP Enroute Charts, FLIP Enroute Supplements, and FLIP Area/Terminal Charts.
3. Terminal: FLIP Instrument Approach Procedures and Standard Instrument Departures (SIDs).

PLANNING.

FLIP Planning Document. The planning document is a three-section, loose-leaf publication with each section bound individually. A different Section II and IIB is produced for each FLIP area (the U.S. also has a Section IIA). There are three FLIP Planning Areas:

Europe, Africa, and Southwest Asia.
North and South America.
Pacific, Australia, and Antarctica.

Following is a brief description of each section.

SECTION I, GENERAL INFORMATION. Contains general information on all FLIPs, a list of FLIP and NOTAM abbreviations, the ICAO NOTAM code, conversion tables, sunrise and sunset tables, and an area of coverage chart.

SECTION II, PLANNING DATA AND PROCEDURES. Contains planning and procedure information for a specific geographic area including index for aeronautical information, special use airspace, flight plans, clearance, etc.

SECTION IIA, MILITARY TRAINING ROUTES UNITED STATES. Published primarily for flight planning and contains detailed data covering VFR and IFR/VFR (Oil Burner) Low Altitude High Speed Training Routes, and Air Refueling Tracks. An accompanying chart provides a graphic depiction of Low Altitude High Speed Training Routes.

SECTION IIB, SPECIAL USE AIRSPACE. Includes a tabulation of all prohibited, restricted, danger, warning, and alert areas, intensive student jet training areas, and known parachute jumping areas.

SECTION III, INTERNATIONAL RULES AND PROCEDURES. Provided for use in all areas of the world, and is the same in all Planning FLIPS. It contains procedures covering international flights, international procedure charts showing ICAO FIR boundaries, altimeter setting procedures (world-wide), Regional VOLMET Plans, communications procedures, and emergency signals.

FLIP Planning Charts. There are three wall planning charts within the DOD FLIP designed primarily for preliminary airway/air route selection and general area orientation, as follows:

1. United States: Low Altitude.
2. Europe and North Africa: Low Altitude.
3. Europe and North Africa: High Altitude.

Foreign Clearance Guide. The Foreign Clearance Guide is not technically a FLIP product but it is used in flight planning. It is issued in independently bound booklets, 8" x 10½", to be inserted in a loose-leaf binder covering the world areas indicated below and includes a General Information Section.

Africa and Southwest Asia
Caribbean and South America
Europe
North America
Pacific, Australia, and Southeast Asia

Information is provided on all foreign nations, U.S. possessions, and U.S. controlled or administered areas outside CONUS, covering aircraft diplomatic clearance and advance notice requirements; personnel clearance and entrance requirements; special restrictions and precautions; general briefing information; material clearance requirements; and requirements of international agencies, unified and specified commands, command activities exercising command prerogatives, joint missions, and advisory groups.

ENROUTE.

FLIP Enroute Charts. FLIP Enroute Charts are 20" x 45" but fold into a compact 5" x 10" size. (The Canada FLIPs are used by DOD but are produced by Canada; as a result they are of slightly different size.) FLIP Enroute Charts portray airway systems, radio aids to navigation, aerodromes, airspace divisions, and other related aeronautical data for Instrument Flight Rule operations.

Two series of Enroute Charts, one for low altitude and a separate one for high altitude are produced for the United States, Europe and North Africa, Alaska, Caribbean/South America, Canada/North Atlantic, and Pacific/Southeast Asia.

(The Pacific/Southeast Asia High Altitude encompasses only Japan, Korea, Philippines, Taiwan.)

One series of Enroute Charts covering both the low and high altitude is produced for Africa/ Southwest Asia and Australia/New Zealand/ Antarctica.

FLIP Enroute Supplements. FLIP Enroute Supplements are 5" x 10" booklets containing aerodrome/facility directory, procedures, and other textual data required to support the Enroute Charts. One Enroute Supplement is published for all FLIP areas except the U.S.

In the United States, there are two Supplements. One Supplement is designed for IFR operations and contains an aerodrome/facility directory, special notices, and procedures. The other is designed for VFR operations and contains a complete listing of VFR and IFR aerodromes, a city/aerodrome cross-reference listing, special notices, emergency procedures, and selected VFR Aerodrome Sketches.

In all other FLIP areas, Aerodrome Sketches are published for a limited number of selected aerodromes and provided in a separate section of the Enroute Supplement. Aerodrome Sketch details include aerodrome identification, city name, distance and direction, and elevation, as well as a diagram of each aerodrome.

Area/Terminal Area Charts. These charts are large scale graphics of selected terminal areas. In the United States, Area Charts are provided primarily as area enlargements; in the foreign areas the Terminal Area Charts are published primarily to provide arrival and/or departure routings. The Area and Terminal Area Charts are printed on the same size sheet as the Enroute Chart (i.e., the terminal area sheet contains several Terminal Area Charts) and are distributed with the Enroute FLIPs.

TERMINAL

FLIP Terminal—Instrument Approach Procedures. These publications contain the approved Instrument Approach Procedures for which a DOD requirement has been established. Each instrument approach procedure shows an aerodrome sketch with additional data as deemed necessary for an approach under IFR conditions. Alaska and Caribbean and South America editions, in addition to the Instrument Approach Procedures, contain departure procedures for selected airfields. The number of volumes vary in each area depending upon the number of required instrument approach procedures. Also in some areas, there are two sets of Terminal FLIPs, one for Low Altitude Procedures and the other for High Altitude Procedures.

FLIP Terminal—Standard Instrument Departures (SIDs). The SID charts published under AFR 55-106, Standard Instrument Departure (SID), provide a "to scale" graphic depiction of the departure procedure plus a supporting textual description. In most cases SID charts are available at Base Operations offices. SIDs for selected civilian and military European Aerodromes are distributed in bound volumes to users of FLIP. The Defense Mapping Agency (DMA) also publishes civilian SIDs for U.S. commercial aerodromes, in bound volumes. Aerodrome sketch detail includes aerodrome identification, city name, distance and direction, and elevation, as well as a diagram of each aerodrome.

FLIPS—MISCELLANEOUS. FLIPs are revised at regular and constant intervals; i.e., every 28 days, once a month, every two months, etc. Since the currency of FLIP information is critical to flight safety, three primary means are used to promulgate changes to the FLIPs in the field.

Military Aviation Notices (MANs). These are normally in textual form but may be graphic. MANs are used to update FLIP Enroute Charts and FLIP Enroute Supplements.

Planning Change Notices (PCN). These are in textual form and are used to update the FLIP Planning Document.

Notices to Airmen (NOTAM). A NOTAM is a message requiring expeditious and wide dissemination by telecommunication means. NOTAMs provide information which is essential to all personnel concerned with flight operations.

FLIP CORRECTIONS. Any correction to FLIP information should be forwarded to DMA immediately by letter, telephone, etc. Self-addressed official correction cards are available in Base Operations for this purpose. There are complete instructions in the FLIPs concerning the methods of notifying DMA about corrections.

SUMMARY

Air traffic control systems have been established throughout the world primarily to promote the safe, orderly, and expeditious flow of air traffic.

Since military aircraft frequently operate in an air traffic control environment, navigators must become thoroughly familiar with all aspects of this system.

Although the pilot is primarily concerned with the navigation of an aircraft when operating under air traffic control, a navigator can assist the pilot and air traffic controllers in three ways: flight planning, position reporting, and alternate actions. An accurate flight plan expedites the issuance of clearances. Position reporting and related ETAs ensure proper separation between aircraft. When an emergency condition exists, prompt and decisive action in flying to the alternate enable the air traffic controllers to clear other traffic with a minimum of delay.

CHAPTER 23

Weather Station Services

As the navigator gains experience, he is able to select the most accurate data available and integrate it into a system of navigation that best fits the existing flight conditions. A knowledge of weather conditions that may be expected in flight is provided aircraft members by the base weather stations. Since weather is a prime factor affecting any flight, it is important that the navigator have a thorough understanding of weather information and the services available to him.

WEATHER CHARTS

The Air Weather Service (AWS) assembles weather information from all regions of the world to provide the Air Force with a world-wide forecasting service. This weather information is collected at regular and frequent intervals from thousands of observing stations. The Air Weather Service has comparatively few stations, therefore, it depends upon civilian weather services for data concerning North America. Ships, aircraft, and stations of other U.S. military services also furnish information. The surface and upper air data observed by stations throughout the world are collected and plotted on surface and constant pressure charts.

Surface Charts

The station circle illustrated in figure 23-1 is used on the facsimile surface charts. The facsimile surface chart (weather map) is received every three hours; from these charts, forecasters obtain a picture of conditions existing at the time of the observations.

When charts are prepared for facsimile transmission by the National Meteorological Center (NMC), AWS Weather Centrals and Forecast Centers, only the most important information such as wind speed and direction, temperature, dew point, and existing weather is included.

The weather analysis depicted on the surface chart in figure 23-2 illustrates:

- Surface frontal position

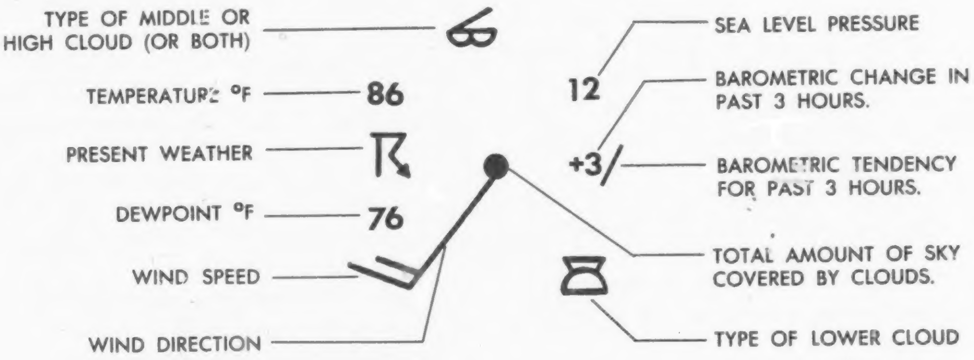

TYPE OF MIDDLE OR HIGH CLOUD (OR BOTH)
TEMPERATURE °F
86
PRESENT WEATHER
DEWPOINT °F
76
WIND SPEED
WIND DIRECTION
SEA LEVEL PRESSURE
12
BAROMETRIC CHANGE IN PAST 3 HOURS.
+3/
BAROMETRIC TENDENCY FOR PAST 3 HOURS.
TOTAL AMOUNT OF SKY COVERED BY CLOUDS.
TYPE OF LOWER CLOUD

Figure 23-1. Plotted Data Around Station Circle on Facsimile Surface Chart

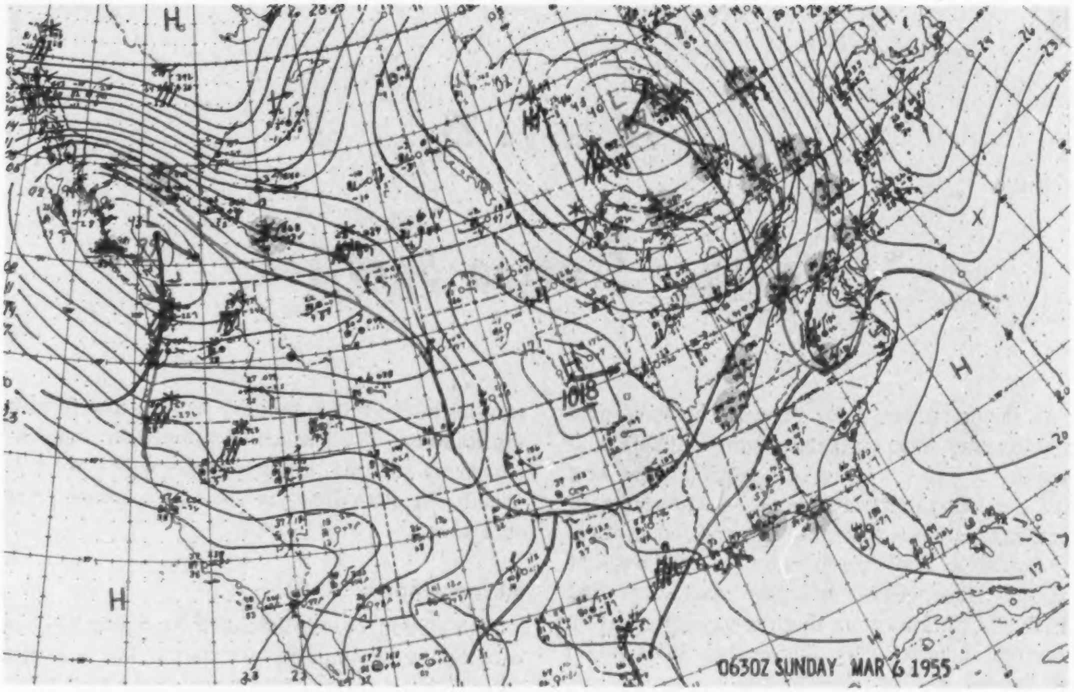


Figure 23-2. Surface Chart Prepared in Weather Station

- Pressure system centers
- Precipitation areas and type
- Isobars (lines connecting points of equal pressure)

Weather which is hazardous to flight is indicated in red symbols.

Surface Prognostic Charts

Surface prognostic (forecast) charts are prepared by the NMC, AWS Weather Centrals and Forecast Centers. They are transmitted via facsimile network and teletype bulletins. These charts can also be prepared by the forecaster when circumstances require. Figure 23-3 shows a prognostic chart which depicts the expected position and orientation of fronts, pressure systems, cloud pattern, and other areas of weather significant to flying operations. Prognostic charts are valid for 12 to 72 hours after the time of preparation; most mission planning is based on a 12- or 18-hour prognostic chart.

After careful study of current and prognostic charts, the forecaster relies on his training, experience, and judgment to make local and operational forecasts.

Constant Pressure Charts

Upper air data for selected standard pressure levels are plotted on constant pressure charts and analyzed. This information is obtained by upper air soundings supplemented by aircraft inflight reports (AIREP). The aircraft report may be the only information available to the forecaster for overwater areas or in areas where there are minimum reporting stations.

The standard pressure levels, for which constant pressure charts (CPC) are constructed and transmitted on facsimile, are shown in figure 23-4. A typical constant pressure chart for the 300-mb level is illustrated in figure 23-5. These charts are prepared from 0000Z and 1200Z observations. The CPC analysis illustrates:

- Contour lines (lines of equal true altitude)
- Isotherms (lines of equal temperature)
- Isotachs (lines of equal wind speed)
- Height centers (highs and lows)
- Region of maximum wind

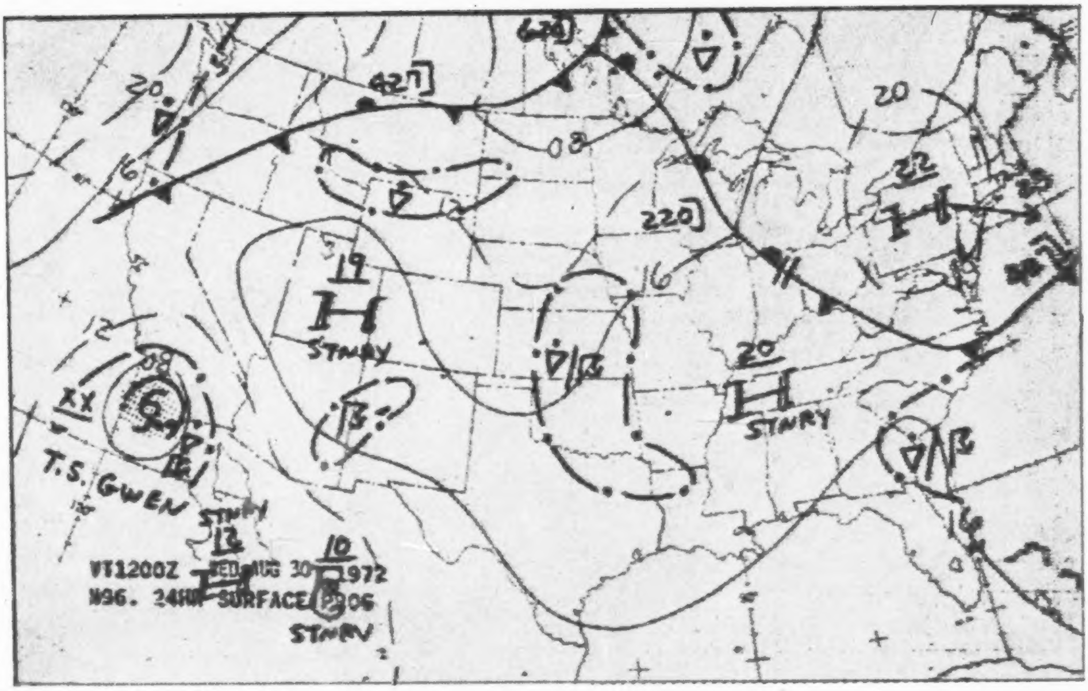


Figure 23-3. Surface Prognostic (Forecast) Chart

Current facsimile constant pressure charts are prepared with computer inputs. All of the five fields of data listed above will not appear on any *given* chart but can be determined from any *series* of charts for all standard levels.

The constant pressure charts, together with surface charts and other charts and diagrams, present a three-dimensional picture of the atmosphere. The combined information from constant pressure charts and surface charts furnishes the user with:

- Wind direction and speed at specific levels
- Temperature and dewpoint depression (temperature dewpoint spread)
- "D" value and expected drift
- Intensity, speed, and direction of movement of frontal and pressure systems
- Amount, type, and intensity of cloud forms and precipitation areas
- Areas of thunderstorms.

From these charts there are derived three general rules which the navigator can safely use for flight planning purposes. These are:

1. The winds blow parallel to the contour lines.
2. The speed of the wind is proportional to the spacing of the contour lines; the closer the contour lines, the stronger the winds.
3. Wind blows clockwise around a high and counterclockwise around a low.

Constant Pressure Prognostic Charts

Constant pressure prognostic charts are prepared by the National Meteorological Center, AWS Weather Centrals and Forecast Centers; they

Pressure Altitude (meters)	(feet)	Temperature (°C)	Pressure (mb)
16,180	53,083	−57	100
11,784	38,662	−57	200
9,164	30,065	−46	300
5,574	18,289	−21	500
3,012	9,882	− 5	700
1,457	4,781	+ 6	850

Mean Sea Level (59°F) 15°C; (29.92" Hg); 1013.25 mb.

Figure 23-4. Standard Pressure Levels

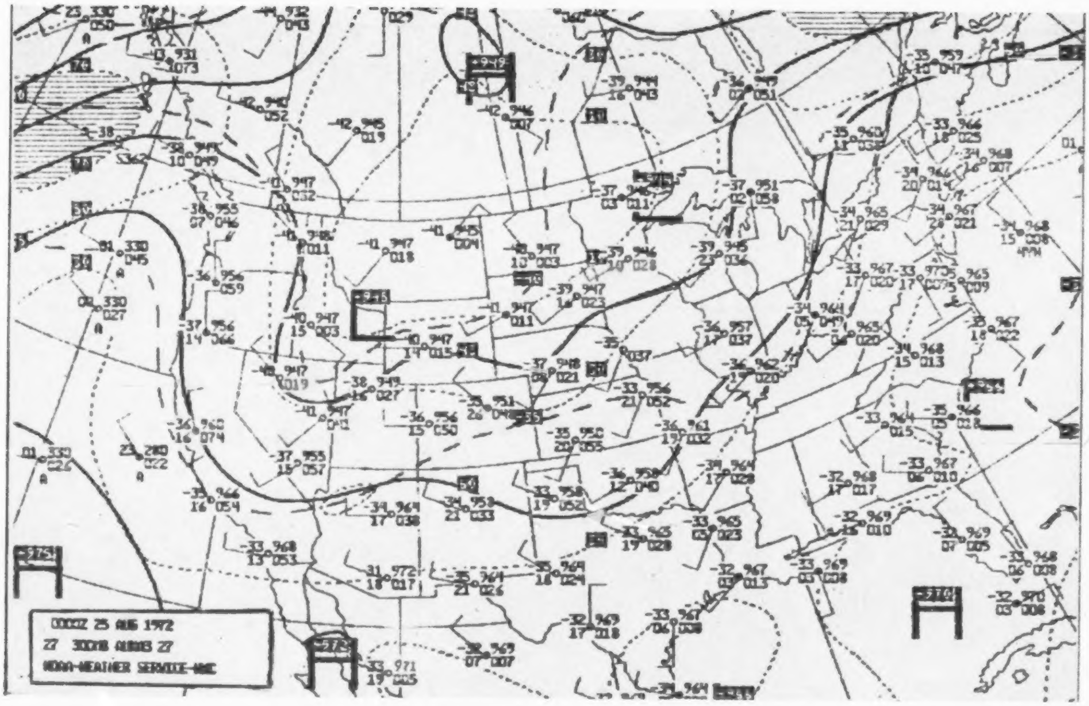


Figure 23-5. 300-mb Constant Pressure Chart

are transmitted to field weather stations via facsimile network. A prognostic chart for the 300-mb level is illustrated in figure 23-6.

These prognostic charts indicate:

- Forecast position and orientation of contours.
- Forecast position of trough lines, and isotachs.
- Forecast position of circulation centers.

NOTE: Remember prognostic charts represent weather conditions anticipated at a specific time, not average weather conditions over a period of time.

Winds Aloft Charts

Winds aloft charts are prepared four times daily from data obtained from upper air observations at 0000Z, 0600Z, 1200Z, and 1800Z. The information collected and plotted on winds aloft charts contains winds for selected levels in the troposphere and stratosphere. Some typical winds aloft charts are shown in figure 23-7.

NOTE: Winds aloft charts do not contain forecast winds, they contain actual winds which can be up to 12 hours old.

Despite the fact that winds from these charts are not necessarily current, they are important to aircrews for computing headings, altitudes, groundspeeds, and time enroute. The detachment forecaster can provide valuable guidance or assistance in determining the representability of these winds.

Summary

With world-wide coverage and various facilities, the Air Weather Service provides vital weather information to aircrews throughout the USAF. It is the job of the navigator to correctly interpret the information provided and use it to best advantage. The foregoing discussion is an introduction to the charts most often used. It is not a complete coverage of the subject. Some of the weather charts discussed in this chapter may not be displayed in all weather stations, but are available upon request.

WEATHER REPORTS AND SYMBOLS

Surface Observations

Surface weather observations are made hourly by Air Weather Service observers or National Weather Service personnel. When a weather ele-

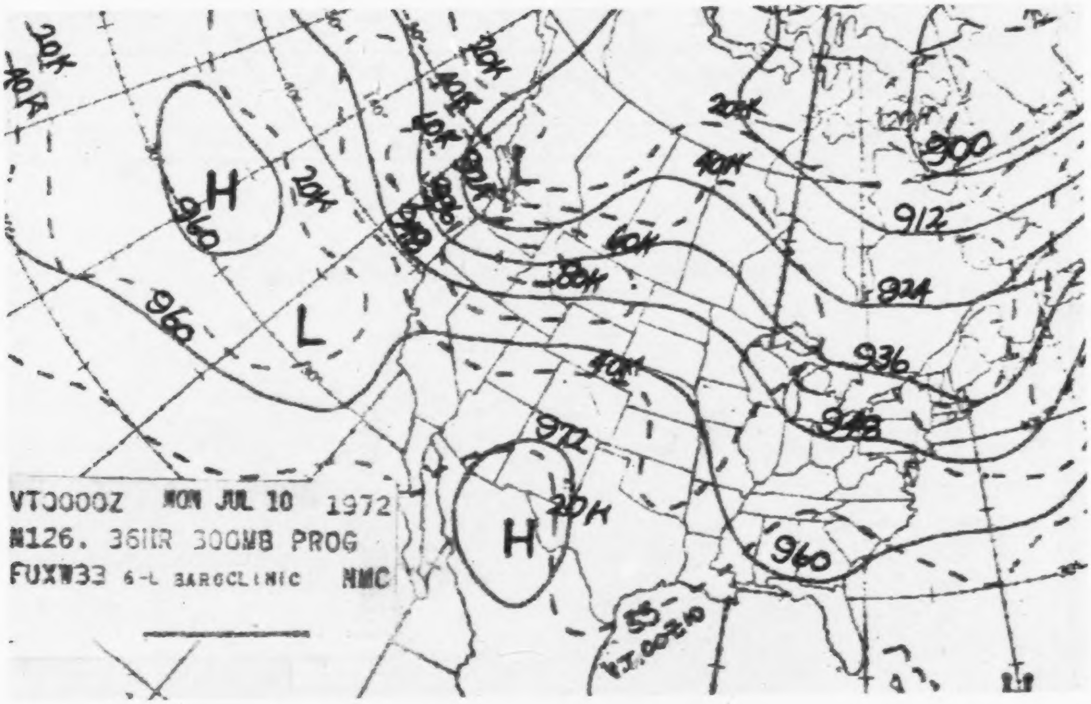

20K
40K
H
960
20K
L
960
80K
40K
20K
40K
60K
80K
900
912
924
936
948
40K
972
20K
H
960
VT0000Z MON JUL 10 1972
N126. 36HR 300MB PROG
FUXW33 6-L BAROCLINIC NMC

Figure 23-6. 300-mb Prognostic Chart

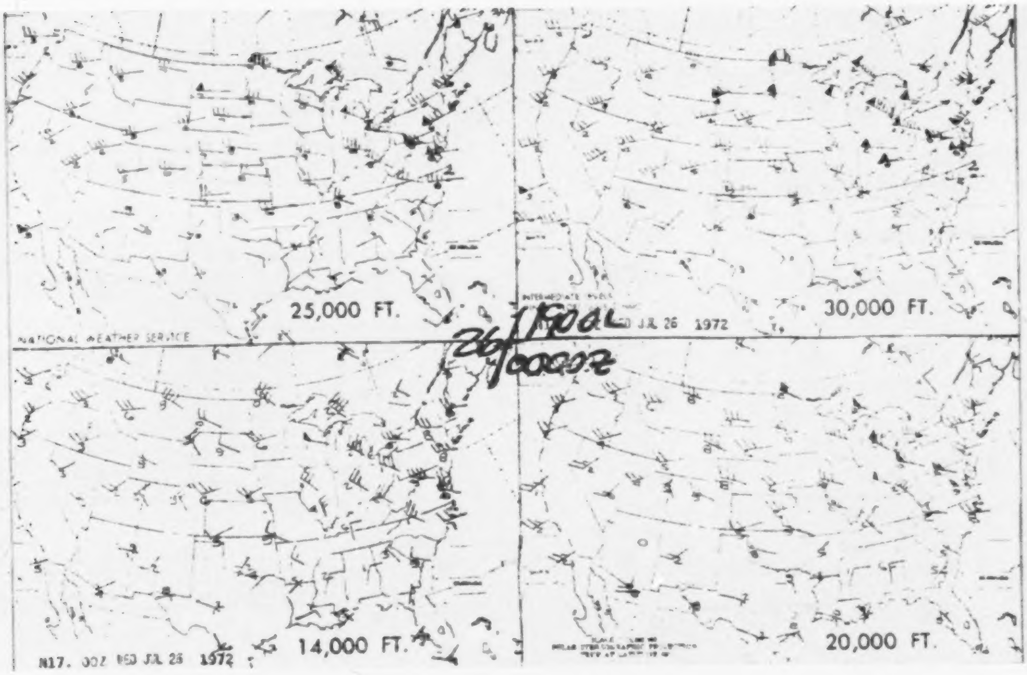
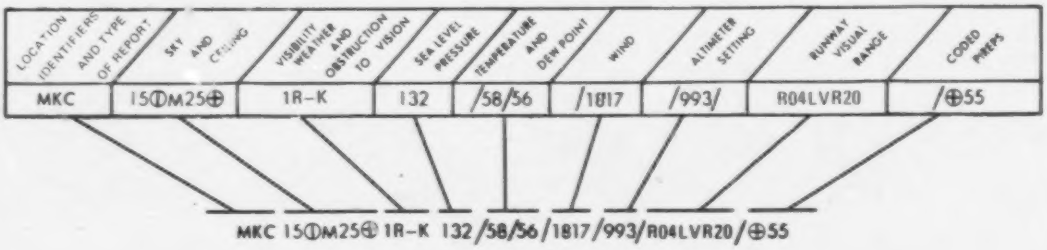

25,000 FT.
30,000 FT.
NATIONAL WEATHER SERVICE
WED JUL 26 1972
26/0000Z
14,000 FT.
20,000 FT.
N17. 00Z WED JUL 26 1972

Figure 23-7. Winds Aloft Charts


LOCATION IDENTIFIERS AND TYPE OF REPORT*
SKY AND CEILING
VISIBILITY WEATHER AND OBSTRUCTION TO VISION
SEA LEVEL PRESSURE
TEMPERATURE AND DEW POINT
WIND
ALTIMETER SETTING
RUNWAY VISUAL RANGE
CODED PIREPS
MKC
15⦶M25⊕
1R–K
132
/58/56
/1817
/993/
R04LVR20
/⊕55
MKC 15⦶M25⊕ 1R–K 132/58/56/1817/993/R04LVR20/⊕55

a. SKY AND CEILING

Sky cover symbols are in ascending order. Figures preceding symbols are heights in hundreds of feet above station.

Sky cover symbols are:

○	Clear: Less than 0.1 sky cover.
⦶	Scattered: 0.1 to less than 0.6 sky cover.
⦷	Broken: 0.6 to 0.9 sky cover.
⊕	Overcast: More than 0.9 sky cover.
—	Thin (When prefixed to the above symbols.)
—X	Partly Obscured: 0.1 to less than 1.0 sky hidden by precipitation or obstruction to vision (bases at surface).
X	Obscured: 1.0 sky hidden by precipitation or obstruction to vision (bases at surface).

Letter preceding height of layer identifies ceiling layer and indicates how ceiling height was obtained. Thus:

A	Aircraft
B	Balloon (ceiling, pilot or raob)
E	Estimated
M	Measured
R	Radar
W	Indefinite
V	Immediately following numerical value indicates a varying ceiling.

b. VISIBILITY

Reported in Statute Miles and Fractions. (V = Variable)

c. WEATHER SYMBOLS

A	Hail
IC	Ice Crystals
IP	Ice Pellets
IPW	Ice Pellet Showers
L	Drizzle
R	Rain
RW	Rain Showers
S	Snow
SG	Snow Grains
SP	Snow Pellets
SW	Snow Showers
T	Thunderstorm
T+	Severe Thunderstorm
ZL	Freezing Drizzle
ZR	Freezing Rain

INTENSITIES are indicated thus:

-Light (no sign) Moderate + Heavy

d. OBSTRUCTION TO VISION SYMBOLS

D	Dust
F	Fog
GF	Ground Fog
H	Haze
IF	Ice Fog
K	Smoke
BD	Blowing Dust
BN	Blowing Sand
BS	Blowing Snow

e. WIND

Direction in tens of degrees from true north, speed in knots, 0000 indicates calm. G indicates gusty. Peak speed follows G or Q when gusts or squalls are reported. The contractions WSHFT followed by local time group in remarks indicates windshift and its time of occurrence. (Knots X 1.15 = statute mi/hr)

EXAMPLES:	3627	360 Degrees, 27 Knots;
	3627G40	360 Degrees, 27 Knots Peak speed in gusts 40 Knots.

f. ALTIMETER SETTING

The first figure of the actual altimeter setting is always omitted from the report.

g. RUNWAY VISUAL RANGE (RVR)

RVR is reported from some stations. Extreme values for 10-minutes prior to observation are given in hundreds of feet. Runway identification precedes the RVR reports.

h. CODED PIREPS

Pilot reports of clouds not visible from ground are coded with MSL height data preceding and/or following sky cover symbol to indicate cloud bases and/or tops, respectively.

NOTE: The RVR reported by Air Force Stations is a 10-minute mean of the visual range in hundreds of feet, e.g., R04LVR30.

i. DECODED REPORT

Kansas City: Record observation, 1500 feet scattered, measured ceiling 2500 feet overcast, visibility 1 mile, light rain, smoke, sea level pressure 1013.2 millibars, temperature 58°F, dewpoint 56°F, wind 180°, 17 knots, altimeter setting 29.93 inches. Runway 04 Left Visual Range 2000 feet, pilot reports top of overcast 5500 feet (MSL).

*TYPE OF REPORT

The omission of type-of-report data identifies a scheduled record observation for the hour specified in the sequence heading, the time of an out-of-sequence, special observation is given as "S" followed by a time group (24 hour clock GMT) e.g., PIT S 0715 XM1. A special indicates a significant change in one or more elements. Local reports are identified by "LCL" and a time group. Locals are transmitted on local teletypewriter circuits only.

Figure 23-8. Decoding Aviation Weather Reports

ment changes significantly, a special observation is taken. Automatic and continuous observations of such elements as the ceiling, visibility, wind, pressure, temperature, and dewpoint are made by weather instruments. These observations are placed in the hands of the using agencies almost instantaneously through the use of modern equipment.

Observations of vital interest to crew members are called Aviation Weather Reports. These reports are transmitted over a world-wide teletype network and received by individual weather stations in the aviation weather reporting code. The reports are collected in sequence and displayed for use by aircrews or by forecasters who brief aircrews.

Aviation Weather Reporting Code

The aviation weather reporting code shown in figure 23-8 is an international weather language. It provides weather personnel with information in a format that is easily understood. A typical report includes the following items:

- Sky condition and ceiling
- Visibility
- Weather and/or obstructions to vision
- Temperature and dewpoint
- Wind
- Altimeter setting
- Remarks

PILOT-TO-FORECASTER SERVICE

Air Weather Service operates a pilot-to-forecaster facility at many bases. These facilities enable airborne crew members to communicate with a forecaster. It is the best and fastest method of obtaining weather information for aircraft in flight. Aircrews use this service to obtain terminal forecasts, altimeter settings, current winds aloft, or other weather data. This also provides a means of passing a pilot report (PIREP), when actual weather encountered differs significantly from the forecast weather. Pilot-to-forecaster service has the highest priority in the weather station except forecaster duties associated with aircraft emergencies or emergency war orders. A chart showing the location of pilot-to-forecaster facilities is published in the DOD Flight Information Publication, Enroute Supplement.

WEATHER FOR FLIGHT PLANNING

Gathering Weather Data

Weather is an extremely important factor in planning any flight mission. These are the steps to follow in gathering weather data:

Step 1. Know exactly what weather information is needed. This normally consists of, but is not necessarily limited to, the weather and winds to expect enroute, the weather at destination and alternate destinations, and the local weather for the time of takeoff and climb-out.

Step 2. Inform the weather forecaster of aircraft type, estimated time of departure (ETD), proposed route and flight altitude, estimated time enroute (ETE), and any additional information that will help him visualize the flight. The more information he is given, the better he is able to provide data pertinent to the flight.

Step 3. When the weather briefing is completed, insure that the following information is complete:

WEATHER FOR TAKEOFF AND CLIMB

- Surface temperature and pressure altitude (or density altitude)
- Surface winds
- Bases and tops of cloud layers
- Visibility
- Precipitation
- Freezing level
- Climb winds

FORECAST WEATHER ENROUTE

- Bases, tops, type, and amount of each cloud layer
- Visibility at flight altitude
- Type, location, intensity, and direction and speed of frontal movements
- Freezing levels
- Temperatures and winds at flight altitude
- Areas of hazardous weather (thunderstorms, hail, icing, and turbulence)
- Areas of good weather (for use in event of an emergency landing enroute).

FORECAST WEATHER FOR DESTINATION AND ALTERNATES

- Bases, tops, type, and amount of cloud layers
- Visibility
- Weather and obstructions to vision
- Freezing level
- Surface wind speed and direction
- Forecast altimeter setting

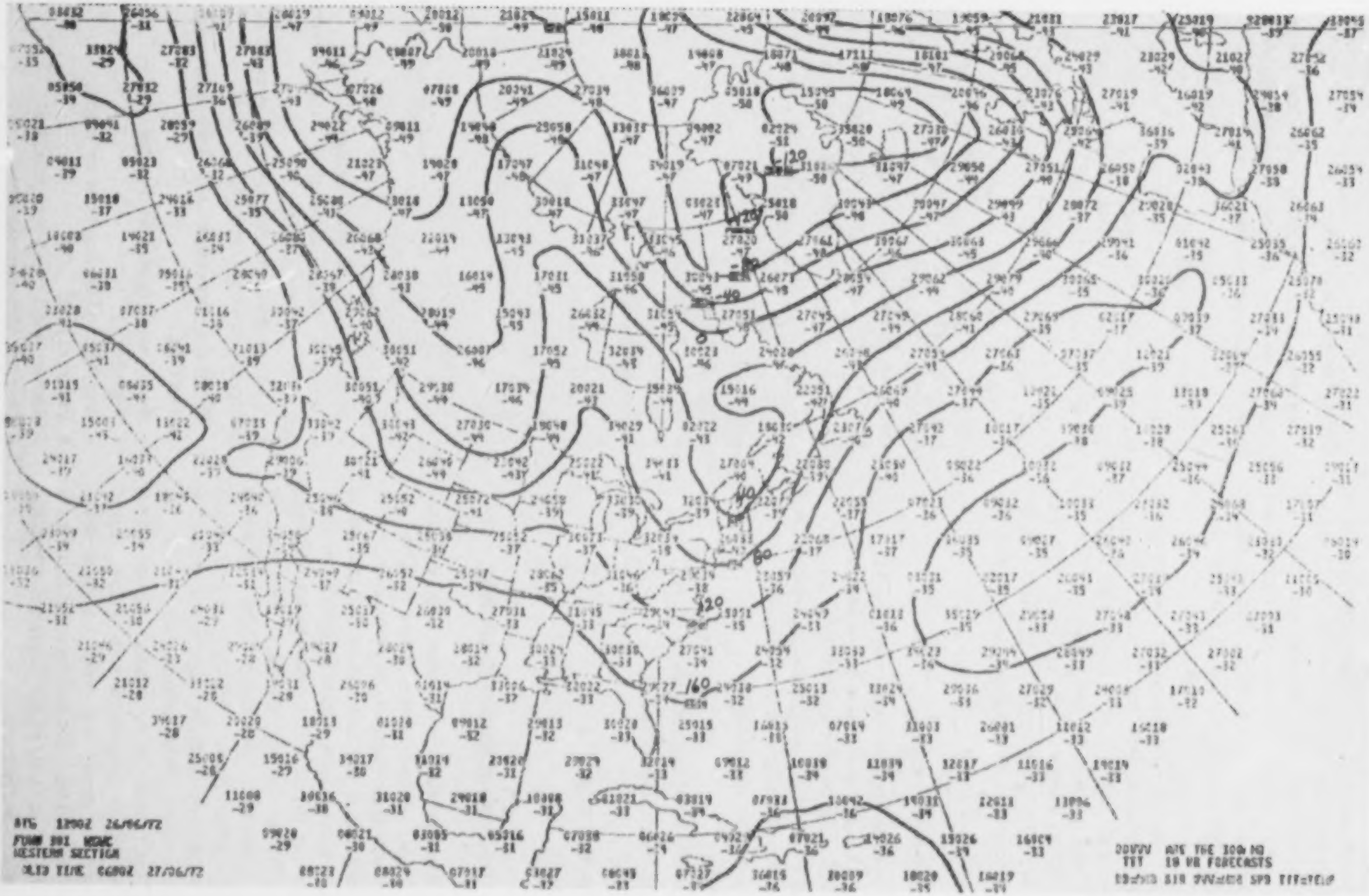
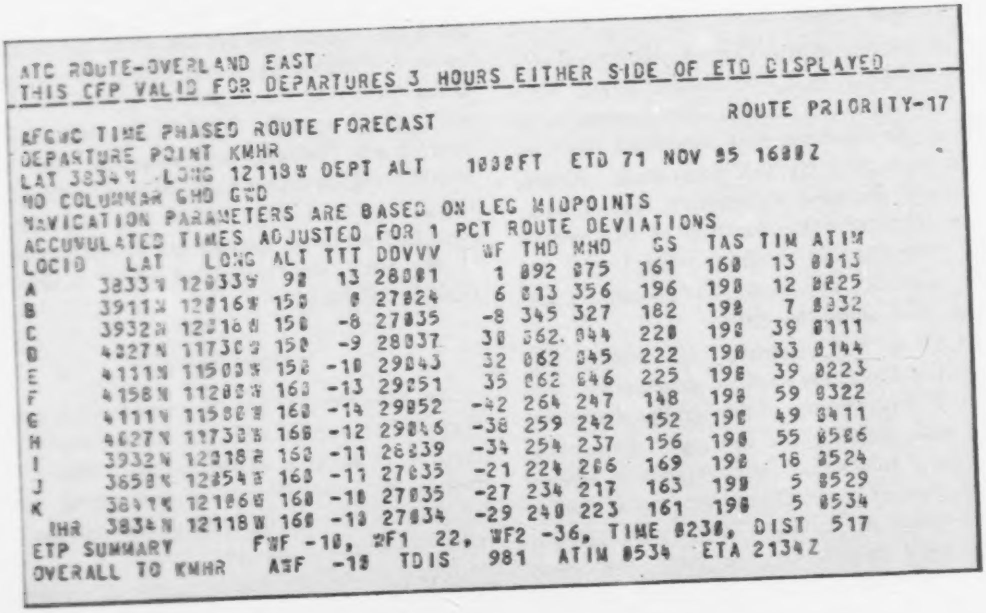

120
40
80
120
160
1200Z 26/06/72
WESTERN SECTION
0600Z 27/06/72
TTT 18 HR FORECASTS

Figure 23-9. "D" Value Flow Chart



```
ATC ROUTE-OVERLAND EAST
THIS CFP VALID FOR DEPARTURES 3 HOURS EITHER SIDE OF ETD DISPLAYED
                                                      ROUTE PRIORITY-17
AFGWC TIME PHASED ROUTE FORECAST
DEPARTURE POINT KMHR
LAT 3834N  LONG 12118W DEPT ALT   1030FT  ETD 71 NOV 05 1600Z
NO COLUMNAR GHD GWD
NAVIGATION PARAMETERS ARE BASED ON LEG MIDPOINTS
ACCUMULATED TIMES ADJUSTED FOR 1 PCT ROUTE DEVIATIONS
LOCID   LAT    LONG ALT TTT DDVVV    WF THD MHD   GS  TAS TIM ATIM
A      3833N 12033W  90  13 28001     1 092 075  161  160  13 0013
B      3911N 12016W 150   0 27024     6 013 356  196  190  12 0025
C      3932N 12016W 150  -8 27035    -8 345 327  182  190   7 0032
D      4327N 11730W 150  -9 28037    30 062 044  220  190  39 0111
E      4111N 11503W 150 -10 29043    32 062 045  222  190  33 0144
F      4158N 11200W 160 -13 29051    35 062 046  225  190  39 0223
G      4111N 11500W 160 -14 29052   -42 264 247  148  190  59 0322
H      4627N 11730W 160 -12 29046   -38 259 242  152  190  49 0411
I      3932N 12018W 160 -11 28039   -34 254 237  156  190  55 0506
J      3658N 12054W 160 -11 27035   -21 224 206  169  190  18 0524
K      3841N 12106W 160 -10 27035   -27 234 217  163  190   5 0529
 MHR   3834N 12118W 160 -10 27034   -29 240 223  161  190   5 0534
ETP SUMMARY        FWF -10, WF1  22, WF2 -36, TIME 0230, DIST  517
OVERALL TO KMHR   AWF  -10  TDIS   981  ATIM 0534  ETA 2134Z
```

Figure 23-10. Computer Flight Plan

Insure that all essential weather elements are included in the briefing and request clarification or additional information concerning any weather data about which there are doubts.

NOTE: If the time of departure is delayed longer than 1½ hours after the time of the briefing, the weather must be revalidated.

In addition to forecaster briefings at the weather stations, some bases use closed-circuit television to brief aircrews. This gives the aircrews a visual weather briefing without going to the weather station. In addition, a small self-briefing weather display is often available to allow the crew to flight plan before getting the final weather briefing.

Applying Weather Data

Getting all the facts and applying them correctly is essential in flight planning. Departure weather can be the deciding factor when an emergency arises soon after takeoff. In some cases, the weather may deteriorate rapidly shortly after takeoff. The navigator must know the winds up to flight altitude in order to compute the distance flown and the fuel consumed during the climb to altitude.

A knowledge of the clouds at flight altitude gives the aircrew an idea of the areas of possible precipitation, icing, turbulence, and other hazards to flight. If the navigator has this knowledge, it increases his ability to make the proper operational decision in the event of an enroute emergency.

"D" Value Flow Charts

A very useful weather chart for the navigator is the high altitude "D" value flow chart shown in figure 23-9. This chart, used primarily by the Strategic Air Command, contains the following information:

- Contours (labeled in 200 or 400 feet "D" value intervals or true altitude of the pressure levels indicated)
- Wind direction and speed
- Temperatures (in degrees celsius)
- Centers of high and low true altitude

The data listed on these charts are invaluable for flight planning and inflight computations. Remember, this is a prognostic chart; it can be made more useful by updating it with current information obtained during flight.

Computer Flight Plans

One of the newer and more sophisticated aids for the navigator is the Computer Flight Plan (CFP). The computer simulates the response of an aircraft to the environmental conditions likely to occur during a given flight. If given track, altitude, true airspeed, and time of departure, the computer may then determine the location of the aircraft and its groundspeed, heading, wind factor, remaining fuel load, and many other factors for any specified point along the route.

The CFP is used extensively by Strategic Air Command and Military Airlift Command on their long-haul flights. The use of this aid has materially reduced flight planning and forecaster preparation times with a substantial improvement in overall accuracy in many cases. During the winter months however errors in individual leg winds and associated wind factors may be large, but when averaged over several legs, the predicted wind factor will normally be very close to the actual value.

CFPs are most useful and accurate for the long flight. To obtain a Computer Flight Plan, the navigator should contact the local weather forecaster preferably 11 to 24 hours before takeoff. If the route is a non-standard route. the forecaster will require specific flight information: Takeoff time, track (latitude and longitude and ICAO identifiers if appropriate and desired) altitude, and true airspeed. A wide variety of navigational options and print-out formats are available and may be requested. An example of a CFP is illustrated in figure 23-10.

SUMMARY

Aviation weather reports provide vital information to the aircrews when planning a flight. These reports can be used to obtain data pertinent to all phases of flight. Data obtained during weather briefing may be rapidly updated through use of the pilot-to-forecaster service.

It is essential that the navigator thoroughly understand all the factors of weather information that are required to plan a flight adequately. Getting all the facts and correctly interpreting them leads to successful completion of each phase of the flight.

CHAPTER 24

Mission Planning

In the air there is little time for lengthy processes of reasoning. Decisions must be made quickly and accurately; therefore, careful planning is essential to any flight. A smooth, successful mission requires a careful step-by-step plan which can be followed from takeoff to landing.

ROUTE DETERMINATION

When planning a route to be flown many factors enter into consideration. The route may be dictated by operational requirements of the mission; it may be a preplanned route; or the navigator may have the prerogative of selecting the route to be flown. In any case, definite factors affect route selection and the navigator must be aware of them.

In most cases a direct route is usually best since it conserves both time and fuel. This, however, can be affected by such things as airways routing, high terrain, and bad weather. The direction of prevailing winds can affect route selection since the proper use of a jet stream often decreases total flying time, even though a direct route is not flown.

Chart Selection

Once a route is established, navigation charts appropriate to the intended flight path should be selected. Correct selection depends mainly on distance to be flown, airspeeds, methods of navigation, and chart accuracy.

TOTAL DISTANCE TO FLY. A great circle is the shortest distance between two points. It is possible to save considerable distance by flying a great circle course, particularly on long-range missions in polar latitudes.

A straight line on a gnomonic chart represents a great circle course. One convenient method of flight planning a great circle course is to plot the entire route on a gnomonic chart, and then transfer coordinates to charts more appropriate for navigation as shown in figure 24-1. Select coordinates at intervals of approximately three hundred nautical miles. Once the route is plotted on the navigation chart, record true courses and distances for each leg of the mission on the flight plan.

CHARTS AND METHODS OF NAVIGATION. The method of navigation is determined by mission requirements and the area over which the mission will progress. Select charts for the mission which are best suited to the navigational techniques chosen. For example, radar missions require charts with representative returns for precision

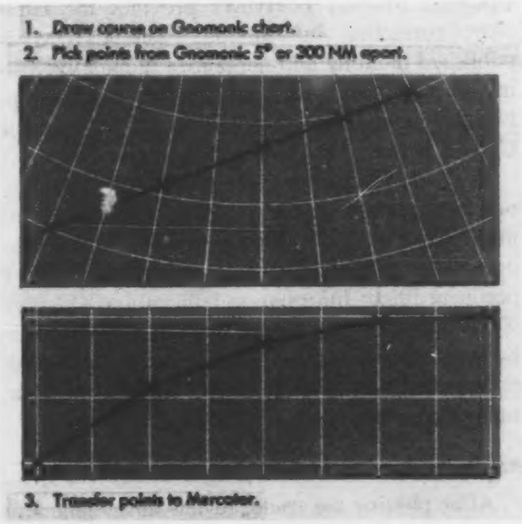

1. Draw course on Gnomonic chart.
2. Pick points from Gnomonic 5° or 300 NM apart.
3. Transfer points to Mercator.

Figure 24-1. Plotting Great Circle Course

fixing, grid missions require charts with a grid overlay, and loran charts are needed for overwater missions.

When several navigation techniques are planned, it may be convenient to use separate charts for different navigation legs. The entire route might be plotted on a JN Chart (1:2,000,000) for premission briefings, reference, etc., the radar navigation legs plotted on an ONC (1:1,000,000) to aid in precision fixing, and the target area legs plotted on a TPC chart (1:500,000).

AIRSPEED. The scale of charts used for air navigation varies inversely with the speed of the aircraft. For example, JN charts have a small scale and contain features appropriate for high speed navigation. Navigation at slower airspeeds requires large scale charts providing more detailed coverage.

CHART CURRENCY. The navigator should always insure that the chart he is using is the latest edition. The following listed documents, published by the Aeronautical Chart and Information Center (ACIC), provide this information.

DOD Bulletin Digest. The Digest is published semi-annually and contains a listing of the current chart editions.

DOD Bulletin. The Bulletin is published monthly to update the Bulletin Digest and to inform Air Force activities of the availability of new aeronautical charts and new editions of previously published charts.

DOD Chart Updating Manual. The DOD Chart Updating Manual (CHUM) provides the latest chart correction information. The CHUM is published monthly and contains a cumulative listing of significant changes and/or additions to Navigation and Planning Charts. A copy of the CHUM is maintained in each base operations.

NOTAMS. Interim aeronautical flight information changes are disseminated by Notices to Airmen (NOTAMS), which are posted in each base operations until the change is provided in all pertinent Flight Information Publications (FLIPs). NOTAMS also provide the most current information on restrictions to flight, reliability of aerodrome facilities and services, enroute hazards, radio aids, etc.

Route Study

After plotting the route, review all inflight procedures before takeoff. What is accomplished in flight is merely a follow-through of what has been planned. For example, annotate fix returns for turning points and important check points and establish a pacing cycle for the various methods of navigation to be used.

Airways

Airways are corridors established by a national government within its airspace to facilitate the navigation and control of air traffic under IFR conditions. Usually, an airway is 10 statute miles wide and follows a route over the ground defined by VORs, TACANs, radio beacons, or other radio aids to navigation.

Generally there are many different airways within a country as evidenced by those established in the United States. (Note that in the U.S. as well as in other countries, there are two sets of airways, one for low altitude and the other for high altitude.) To distinguish one airway from another, each has its own designator; i.e., V (low altitude), J (high altitude). These designators simplify the preparation of a flight plan and improve the communications between aircrews and air traffic controllers.

Military aircrews use the airways for flight operations primarily during IFR weather, military mission permitting. The most current and complete information on airways is contained on the DOD Flight Information Publications. There is much information included in these documents which has significant interest to navigators, such as magnetic courses, distances, compulsory reporting points, frequencies and call signs of radio aids to navigation, etc.

Alternate Aerodrome

This is an aerodrome where an aircraft intends to land if weather conditions prevent landing at scheduled destination. Occasionally an aerodrome may also be identified as an alternate for takeoff purposes. This is at the direction of a major command which authorizes the use of lower minimums for takeoff than for landing. AFM 60-16, General Flight Rules, establishes the conditions under which an alternate aerodrome must be selected and when it will be used by USAF aircrews.

Emergency Aerodromes

During flight planning, select certain aerodromes along the planned flight route as possible emergency landing areas; then annotate these aerodromes on the charts for quick reference. Consider the following factors when selecting an emergency aerodrome: type of aircraft, weather conditions, runway length, runway weight bearing capacity, runway lighting, and radio navigation aids.

Summary

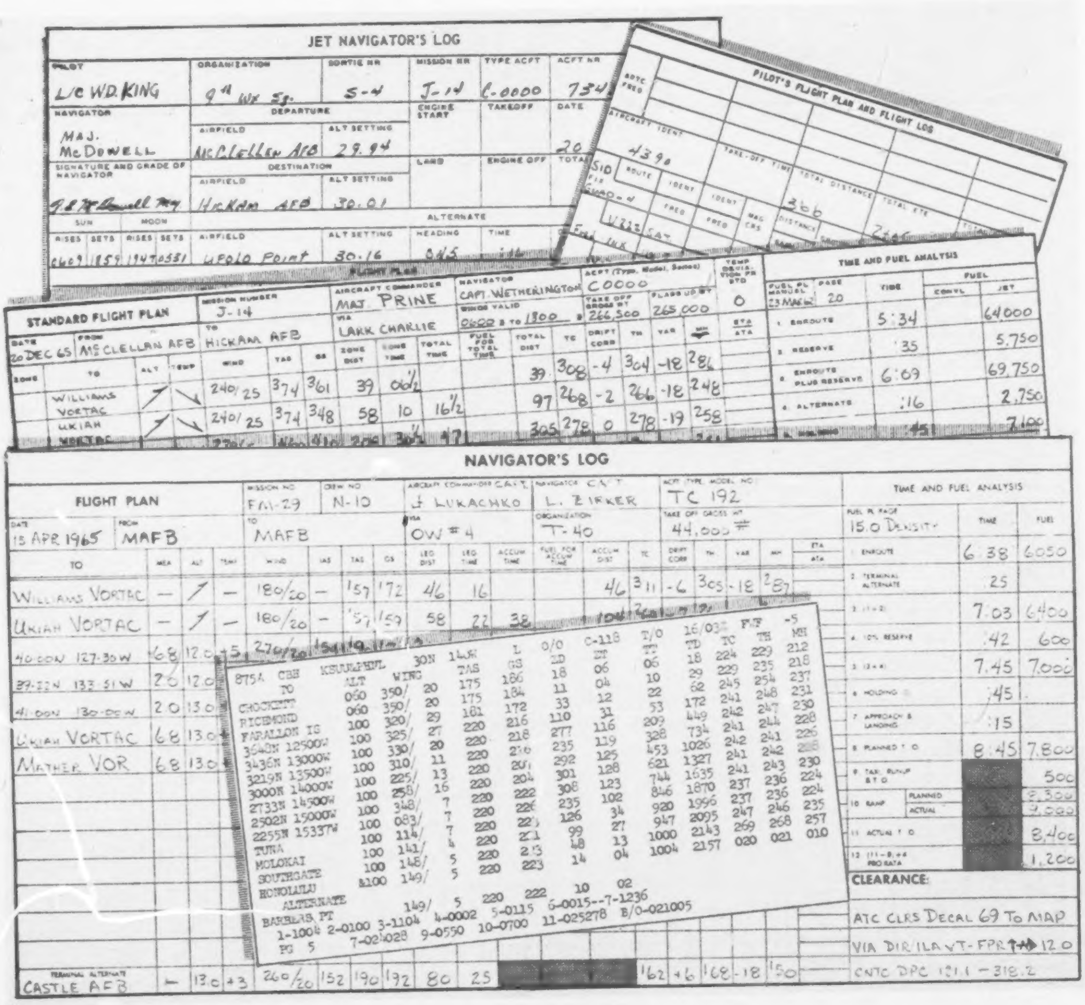
Preflight planning is an extremely important factor in preparation for any flight mission. Careful route determination, coupled with proper selection and annotation of charts, insures a smooth, successful flight. Remember, the results are only as good as the plan.

NAVIGATIONAL DATA

Flight Plan

AF Form 21, Navigator's Log, is designated for general navigation use. To meet specialized operational requirements, major commands may prescribe and issue additional or substitute navigator's logs.

The completed flight plan forms shown in Figure 24-2 are typical Air Force flight plans. There are only slight differences in the flight plan columns; the main differences are in the "Time and Fuel Analysis" sections. The headings and columns on the forms are self-explanatory. The column



JET NAVIGATOR'S LOG

PILOT	ORGANIZATION	SORTIE NR	MISSION NR	TYPE ACFT	ACFT NR
L/C WD. KING	9th Wx Sq.	5-4	J-14	C-0000	734

NAVIGATOR: MAJ. McDOWELL

DEPARTURE — AIRFIELD: McClellan AFB — ALT SETTING: 29.94

ENGINE START — TAKEOFF — DATE: 20

SIGNATURE AND GRADE OF NAVIGATOR: J. E. McDowell Maj

DESTINATION — AIRFIELD: Hickam AFB — ALT SETTING: 30.01

LAND — ENGINE OFF — TOTAL

ALTERNATE — AIRFIELD: Upolo Point — ALT SETTING: 30.16 — HEADING: 045 — TIME

SUN RISES	SUN SETS	MOON RISES	MOON SETS
0609	1859	1947	0551

PILOT'S FLIGHT PLAN AND FLIGHT LOG

ARTC FREQ

AIRCRAFT IDENT: 4390

TAKE-OFF TIME — TOTAL DISTANCE: 366 — TOTAL ETE

SID — ROUTE — IDENT — FREQ — IDENT — FREQ — MAG CRS — DISTANCE

FLIGHT PLAN

STANDARD FLIGHT PLAN

MISSION NUMBER: J-14

AIRCRAFT COMMANDER: MAJ PRINE

NAVIGATOR: CAPT. WETHERINGTON

ACFT (Type, Model, Series): C0000

TEMP DEVIATION FR STD: 0

DATE: 20 DEC 65 — FROM: McCLELLAN AFB — TO: HICKAM AFB — VIA: LARK CHARLIE

WINDS VALID: 0600 Z TO 1800 Z

TAKE OFF GROSS WT: 266,500 — PLANNED WT: 265,000

ZONE	TO	ALT	TEMP	WIND	TAS	GS	ZONE DIST	ZONE TIME	TOTAL TIME	FUEL FOR TOTAL TIME	TOTAL DIST	TC	DRIFT CORR	TH	VAR	MH	ETA / ATA
		↗	↘	240/25	374	361	39	06½			39	308	-4	304	-18	286	
	WILLIAMS VORTAC	↗	↘	240/25	374	348	58	10	16½		97	268	-2	266	-18	248	
	UKIAH VORTAC							30½	47		305	278	0	278	-19	258	

TIME AND FUEL ANALYSIS

FUEL PL MANUAL 23 MAR 62	PAGE 20	TIME	FUEL CONVL	FUEL JET
1. ENROUTE		5:34		64000
2. RESERVE		:35		5,750
3. ENROUTE PLUS RESERVE		6:09		69,750
4. ALTERNATE		:16		2,750
5. HOLDING		:45		7,100

NAVIGATOR'S LOG

FLIGHT PLAN

MISSION NO: FM-29 — CREW NO: N-10 — AIRCRAFT COMMANDER: CAPT. J. LUKACHKO — NAVIGATOR: CAPT. L. ZIRKER — ACFT (TYPE, MODEL, NO): TC 192

DATE: 15 APR 1965 — FROM: MAFB — TO: MAFB — VIA: OW #4 — ORGANIZATION: T-40 — TAKE OFF GROSS WT: 44,000 #

TO	MEA	ALT	TEMP	WIND	IAS	TAS	GS	LEG DIST	LEG TIME	ACCUM TIME	FUEL FOR ACCUM TIME	ACCUM DIST	TC	DRIFT CORR	TH	VAR	MH	ETA / ATA
WILLIAMS VORTAC	—	↗	—	180/20	—	157	172	46	16			46	311	-6	305	-18	287	
UKIAH VORTAC	—	↗	—	180/20	—	157	159	58	22	38		104						
40-00N 127-30W	68	12.0	+5	270/20	154	149												
39-22N 133-51W	20	12.0																
41-00N 130-00W	20	13.0																
UKIAH VORTAC	68	13.0																
MATHER VOR	68	13.0																
TERMINAL ALTERNATE CASTLE AFB	—	13.0	+3	260/20	152	190	192	80	25				162	+6	168	-18	150	

TIME AND FUEL ANALYSIS

FUEL PL PAGE 15.0 DENSITY		TIME	FUEL
1. ENROUTE		6:38	6050
2. TERMINAL ALTERNATE		:25	
3. (1+2)		7:03	6400
4. 10% RESERVE		:42	600
5. (3+4)		7.45	7.000
6. HOLDING		:45	
7. APPROACH & LANDING		:15	
8. PLANNED T O		8:45	7.800
9. TAXI, RUNUP & T O			500
10. RAMP	PLANNED		8,300
	ACTUAL		9,000
11. ACTUAL T O			8,400
12. (11-8)+4 PRO RATA			1,200

CLEARANCE:

ATC CLRS DECAL 69 TO MAP

VIA DIR ILA VT-FPR → 12.0

CNTC DPC 121.1 — 318.2

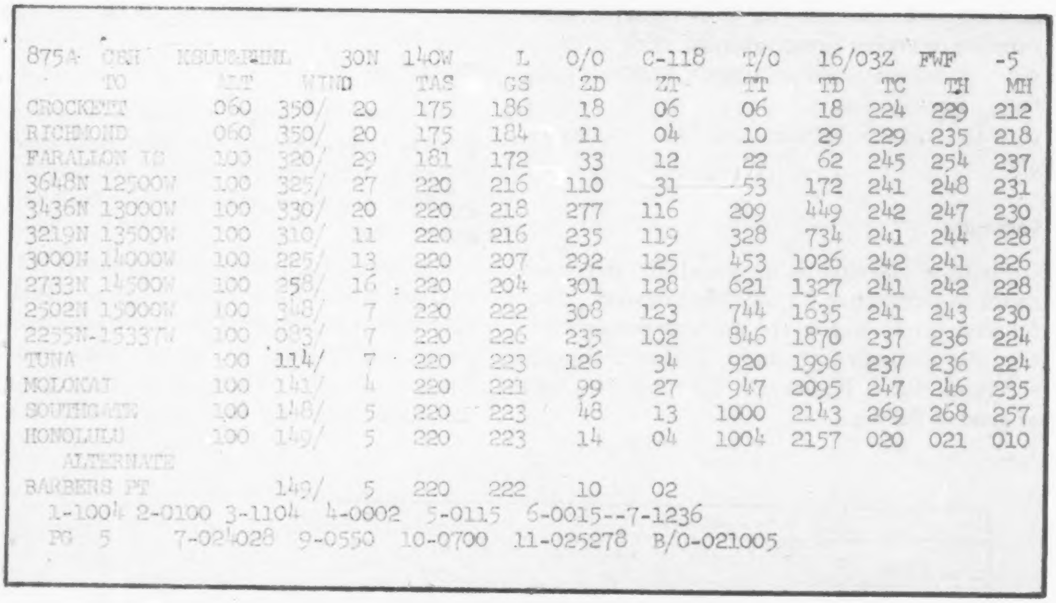
875A CBH KSUU/PHNL 30N 14W L 0/0 C-118 T/0 16/03Z F/F -5

TO	ALT	WIND		TAS	GS	ZD	ET	TT	TD	TC	TH	MH
CROCKETT	060	350/	20	175	186	18	06	06	18	224	229	212
RICHMOND	060	350/	20	175	184	11	04	10	29	229	235	218
FARALLON IS	100	320/	29	181	172	33	12	22	62	245	254	237
3648N 12500W	100	325/	27	220	216	110	31	53	172	241	248	231
3436N 13000W	100	330/	20	220	218	277	116	209	449	242	247	230
3219N 13500W	100	310/	11	220	216	235	119	328	734	241	244	228
3000N 14000W	100	225/	13	220	201	292	125	453	1026	242	241	226
2733N 14500W	100	258/	16	220	204	301	128	621	1327	241	242	[illegible]
2502N 15000W	100	348/	7	220	222	308	123	744	1635	241	243	230
2255N 15337W	100	083/	7	220	226	235	102	846	1870	237	236	224
TUNA	100	114/	7	220	[illegible]	126	34	920	1996	237	236	224
MOLOKAI	100	141/	4	220	221	99	27	947	2095	247	246	235
SOUTHGATE	100	148/	5	220	213	48	13	1000	2143	269	268	257
HONOLULU	&100	149/	5	220	223	14	04	1004	2157	020	021	010
ALTERNATE												
BARBERS PT		149/	5	220	222	10	02					

1-1004 2-0100 3-1104 4-0002 5-0115 6-0015--7-1236

PG 5 7-024028 9-0550 10-0700 11-025278 B/0-021005

Figure 24-2. Typical Flight Plans and Logs



```
875A CBH  KSUU&PHNL     30N  140W       L    0/0    C-118    T/0    16/03Z  FWF    -5
      TO          ALT     WIND      TAS     GS     ZD      ZT     TT      TD    TC     TH    MH
CROCKETT          060   350/  20    175    186     18      06     06      18   224    229   212
RICHMOND          060   350/  20    175    184     11      04     10      29   229    235   218
FARALLON IS       100   320/  29    181    172     33      12     22      62   245    254   237
3648N 12500W      100   325/  27    220    216    110      31     53     172   241    248   231
3436N 13000W      100   330/  20    220    218    277     116    209     449   242    247   230
3219N 13500W      100   310/  11    220    216    235     119    328     734   241    244   228
3000N 14000W      100   225/  13    220    207    292     125    453    1026   242    241   226
2733N 14500W      100   258/  16  : 220    204    301     128    621    1327   241    242   228
2502N 15000W      100   348/   7    220    222    308     123    744    1635   241    243   230
2255N-15337W      100   083/   7    220    226    235     102    846    1870   237    236   224
TUNA              100   114/   7    220    223    126      34    920    1996   237    236   224
MOLOKAI           100   141/   4    220    221     99      27    947    2095   247    246   235
SOUTHGATE         100   148/   5    220    223     48      13   1000    2143   269    268   257
HONOLULU          100   149/   5    220    223     14      04   1004    2157   020    021   010
   ALTERNATE
BARBERS PT              149/   5    220    222     10      02
  1-1004 2-0100 3-1104  4-0002  5-0115  6-0015--7-1236
  PG  5      7-024028  9-0550  10-0700  11-025278  B/0-021005
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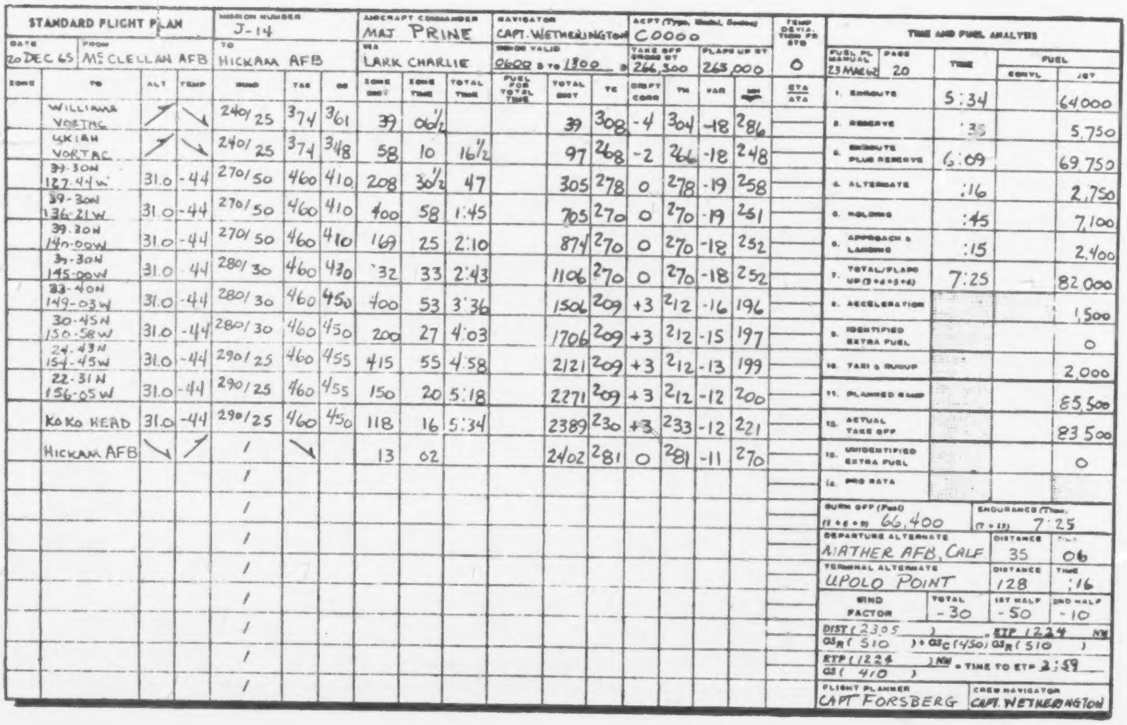
Figure 24-3. Computer Flight Plan



STANDARD FLIGHT PLAN	MISSION NUMBER J-14	AIRCRAFT COMMANDER MAJ PRINE	NAVIGATOR CAPT. WETHERINGTON
DATE 20 DEC 65	FROM McCLELLAN AFB	TO HICKAM AFB	VIA LARK CHARLIE
WINDS VALID 0600 Z to 1800 Z	ACFT (Type, Model, Series) C0000	TAKE OFF GROSS WT 266,300	FLAPS UP WT 265,000
TEMP DEVIATION FROM STD 0			

ZONE	TO	ALT	TEMP	WIND	TAS	GS	ZONE DIST	ZONE TIME	TOTAL TIME	FUEL FOR TOTAL TIME	TOTAL DIST	TC	DRIFT CORR	TH	VAR	MH	ETA/ATA
	WILLIAMS VORTAC	↗	↘	240/25	374	361	39	06½			39	308	-4	304	-18	286	
	UKIAH VORTAC	↗	↘	240/25	374	348	58	10	16½		97	268	-2	266	-18	248	
	39-30N 127-44W	31.0	-44	270/50	460	410	208	30½	47		305	278	0	278	-19	258	
	39-30N 136-21W	31.0	-44	270/50	460	410	400	58	1:45		705	270	0	270	-19	251	
	39-30N 140-00W	31.0	-44	270/50	460	410	169	25	2:10		874	270	0	270	-18	252	
	39-30N 145-00W	31.0	-44	280/30	460	430	232	33	2:43		1106	270	0	270	-18	252	
	33-40N 149-03W	31.0	-44	280/30	460	450	400	53	3:36		1506	209	+3	212	-16	196	
	30-45N 150-58W	31.0	-44	280/30	460	450	200	27	4:03		1706	209	+3	212	-15	197	
	24-43N 154-45W	31.0	-44	290/25	460	455	415	55	4:58		2121	209	+3	212	-13	199	
	22-31N 156-05W	31.0	-44	290/25	460	455	150	20	5:18		2271	209	+3	212	-12	200	
	KOKO HEAD	31.0	-44	290/25	460	450	118	16	5:34		2389	230	+3	233	-12	221	
	HICKAM AFB	↘	↗	/	↘		13	02			2402	281	0	281	-11	270	
				/													
				/													
				/													
				/													
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				/													
				/													

TIME AND FUEL ANALYSIS

FUEL PL MANUAL 23 MAR 62 / PAGE 20	TIME	FUEL CONVL	FUEL JET
1. ENROUTE	5:34		64000
2. RESERVE	:35		5,750
3. ENROUTE PLUS RESERVE	6:09		69,750
4. ALTERNATE	:16		2,750
5. HOLDING	:45		7,100
6. APPROACH & LANDING	:15		2,400
7. TOTAL/FLAPS UP (3+4+5+6)	7:25		82,000
8. ACCELERATION			1,500
9. IDENTIFIED EXTRA FUEL			0
10. TAXI & RUNUP			2,000
11. PLANNED RAMP			85,500
12. ACTUAL TAKE OFF			83,500
13. UNIDENTIFIED EXTRA FUEL			0
14. PRO RATA			

BURN OFF (Fuel) (1+8+9) 66,400

ENDURANCE (Time) (7+13) 7:25

DEPARTURE ALTERNATE MATHER AFB, CALF	DISTANCE 35	TIME 06
TERMINAL ALTERNATE UPOLO POINT	DISTANCE 128	TIME :16

WIND FACTOR	TOTAL	1ST HALF	2ND HALF
	-30	-50	-10

$$\frac{\text{DIST}(2305)\times GS_R(510)}{GS_C(450)+GS_R(510)} = \text{ETP } 1224 \text{ NM}$$

$$\frac{\text{ETP}(1224)\text{ NM}}{GS(410)} = \text{TIME TO ETP } 2{:}59$$

FLIGHT PLANNER CAPT FORSBERG

CREW NAVIGATOR CAPT. WETHERINGTON

Figure 24-4. Standard Flight Plan

labeled "To" contains the navigational check points.

On some standard routes, computer flight plans are available. Weather and route data are inserted into a computer and the flight plan is automatically completed as shown in figure 24-3. The navigator need only compute the additional information he needs, such as fuel analysis, equal time point (ETP), etc.

Fuel Analysis

FUEL ANALYSIS FOR JET AIRCRAFT. The following example of computation of fuel requirements for the jet flight plan is shown in figure 24-4.

Enroute Fuel. Enroute fuel is determined with a fuel graph such as the constant altitude graph depicted in figure 24-5. Each type of aircraft has a series of fuel graphs based on: (1) aircraft gross weight, (2) pressure or density altitude, (3) true airspeed or Mach number, and (4) on some aircraft, the aerodynamic drag of external stores.

To compute the enroute fuel, extract the total enroute time from the flight plan and log it in block 1 of the time column in the fuel analysis section. Enter the fuel graph (figure 24-5) along the top or bottom with the total enroute flying time (5:34) and proceed vertically to the lines labeled "Fuel Consumed." The estimated amount of fuel consumed varies with flight level temperature. Notice, therefore, that there are lines on the graph representing the fuel consumed at the centigrade temperature for a standard atmosphere (STD Day) and lines representing the fuel consumed in an atmosphere 20°C above and 20°C below the standard. The block labeled "TEMP DEVIATION FR STD" (figure 24-4) shows the temperature deviation from standard to be zero on the day of the flight. Therefore, the STD fuel line on the fuel graph is used, yielding a value of 64,000 lbs of fuel. This is entered in block 1 of the jet fuel column in figure 24-4.

Reserve Fuel. Reserve fuel is the amount of fuel needed to fly an additional ten percent of enroute flying time from departure to destination to the alternate. It is determined *after* computing the "enroute plus reserve" fuel by subtracting block 1 from block 3. Reserve time is determined to be 35 minutes and is computed as ten percent of enroute time (5:34) plus the time to the alternate (:16).

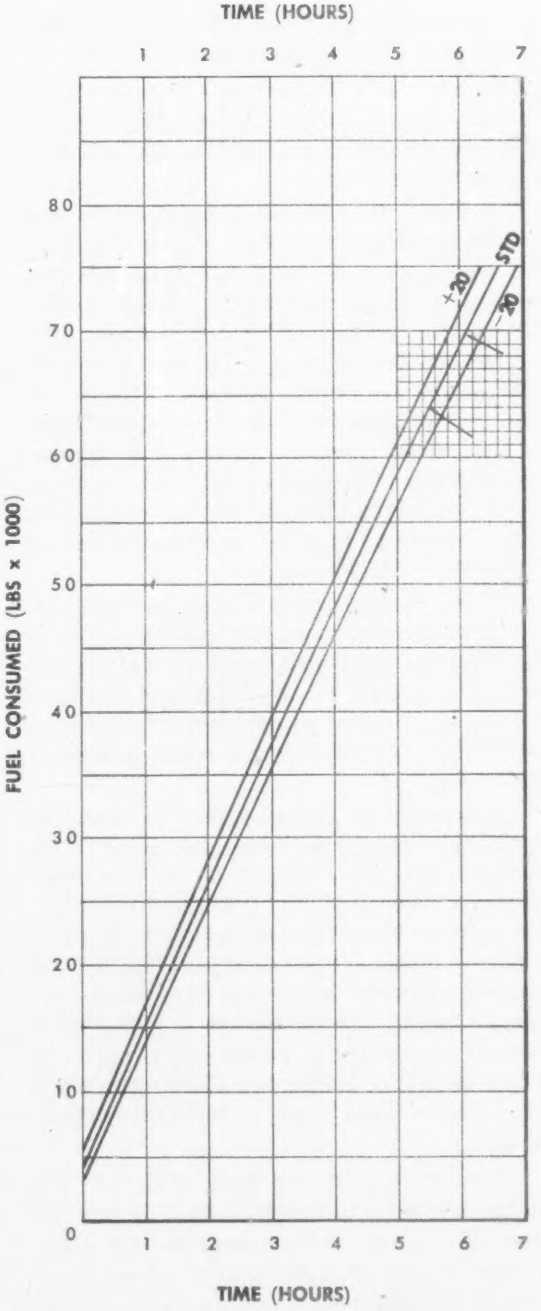


Figure 24-5. Constant Altitude Fuel Graph

Enroute Plus Reserve. Enroute time (5:34) and reserve time (35 minutes) are added together to obtain the enroute plus reserve time (6:09). The fuel (69,750 lbs) for this time is extracted from the fuel graph in the same manner as the enroute fuel, and is logged in block 3.

Alternate Fuel. The terminal alternate in this example is Upolo Point. The distance and time to it from destination are logged at the bottom of the fuel analysis section.

The fuel to the alternate is based on the fuel flow for the gross weight of the aircraft at destination, the true airspeed, and altitude to the alternate. Some flight manuals for jet aircraft include graphs designed for computing fuel to the alternate, but the fuel can also be computed by adding enroute time and the time to the alternate. This time is then used to extract the total fuel required from takeoff to the alternate. In this case, enroute time plus time to alternate (5:50) yields a requirement of 66,750 lbs. The enroute fuel (64,000 lbs) is then subtracted from this to obtain the fuel to the alternate (2,750 lbs).

Holding Fuel. Adverse weather, air traffic, or aircraft malfunction in the terminal area may force the aircraft to "hold" in the local area for a period of time before landing. The amount of computed holding fuel is based on delays of 45 minutes at 10,000 feet, or one hour and fifteen minutes at 20,000 feet.

Gross weight at destination must be computed and used in entering the holding fuel graph shown in figure 24-6. To do this, subtract the enroute fuel from "flaps-up-weight" (265,000 — 64,000= 201,000 lbs). Enter along the bottom of the graph with gross weight at destination (201,000 lbs) and proceed vertically to the line representing the planned holding time (45 minutes at 10,000 feet). Proceed horizontally to the line indicating the required amount of holding fuel (7,100 lbs). Enter this value in block 5 of the flight plan) figure 24-4).

Approach and Landing Fuel. Approach and landing fuel is the fuel required from the terminal fix to the runway. This is computed for a prescribed amount of time (usually 15 minutes). The amount of fuel needed for approach and landing varies with the aircraft. In this example, it is 2,400 lbs.

Total/Flaps Up: Total or Flaps Up is the required amount of fuel for enroute, reserve, alternate, holding, and approach and landing. It is a cumulative total of blocks 3, 4, 5, and 6 (82,000 lbs).

Acceleration Fuel. Acceleration fuel is the amount of fuel used by the aircraft during takeoff from brake release to flap retraction, predetermined for aircraft type (in this example, 1,500 lbs).

Identified Extra Fuel. Identified extra fuel is any additional fuel needed for special reasons dictated by mission requirements. It is zero in this example.

Taxi and Runup. Taxi and runup is the fuel needed for taxiing and engine runup. It is usually a predetermined value for each type of aircraft. For the aircraft in this example, 2,000 lbs is used.

Planned Ramp Fuel. Planned ramp fuel is the amount of fuel required at engine start to complete the mission. It is the sum of blocks 7, 8, 9, and 10 (85,500 lbs).

Actual Takeoff Fuel. Actual takeoff fuel is the fuel remaining at the beginning of the takeoff roll. It can be computed by subtracting the fuel used during taxi and runup (2,000) from the total fuel serviced (85,500) or by reading the fuel gages at the start of takeoff. This is entered in block 12 (83,500).

Unidentified Extra Fuel. Unidentified extra fuel is additional fuel over and above that required by the flight plan. It is the difference between planned ramp fuel and actual ramp fuel. In this example, it is zero.

Burn Off (Fuel). Burn off fuel is the planned amount of fuel to be used after takeoff. This value subtracted from takeoff gross weight pro-

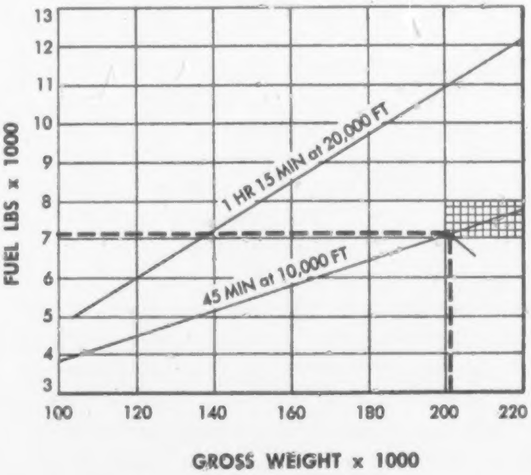


Figure 24-6. Holding Fuel Graph (Jet)

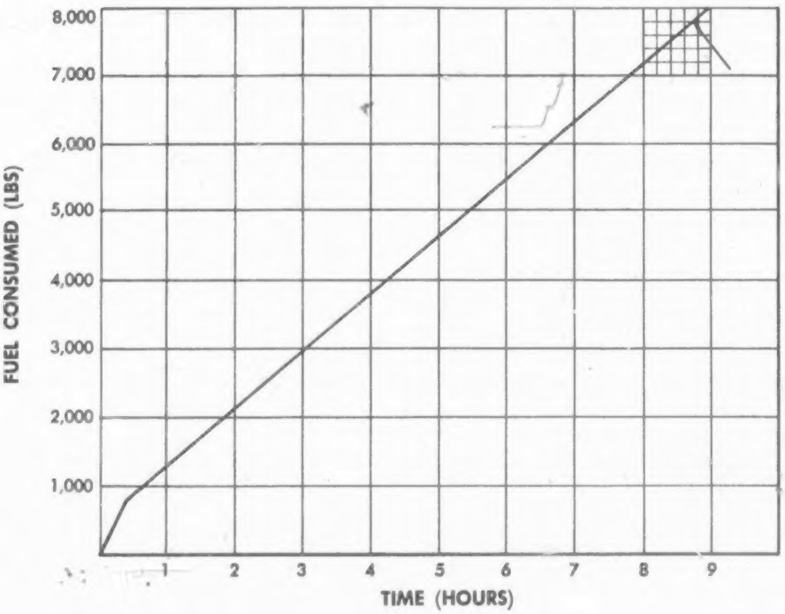
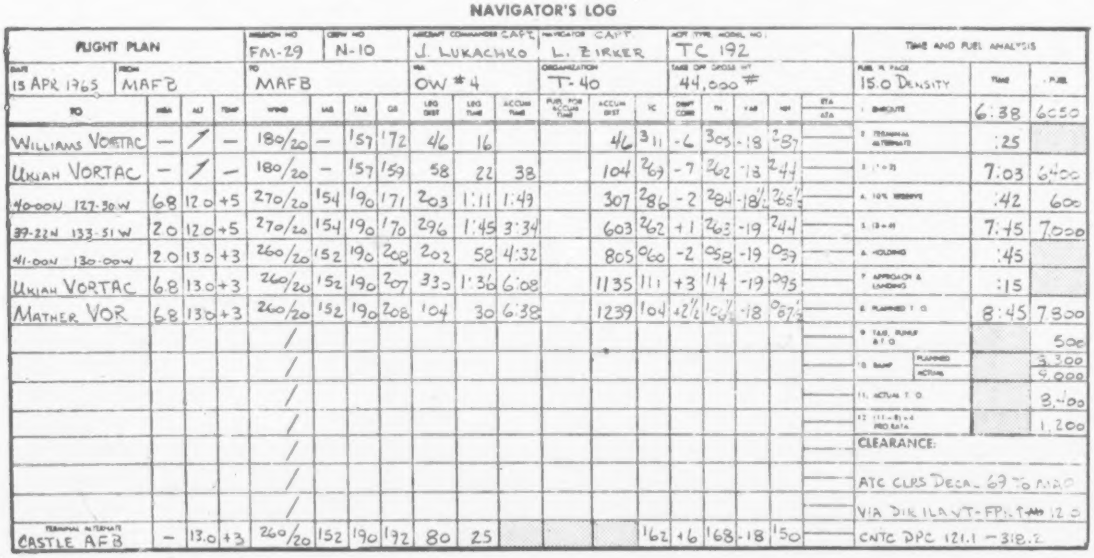


Figure 24-7. Fuel Graph (Conventional)

duces the predicted gross weight of the aircraft on landing.

FUEL ANALYSIS FOR CONVENTIONAL AIRCRAFT. As with jet aircraft, each type of conventional aircraft has a series of fuel graphs. Each graph is based on density altitude, takeoff gross weight, and true airspeed. The fuel graph shown in figure 24-7 is used in completing blocks 1 through 8 on the flight plan shown in figure 24-8.

To use the fuel graph, enter along the top or



NAVIGATOR'S LOG

FLIGHT PLAN
MISSION NO FM-29
CREW NO N-10
AIRCRAFT COMMANDER CAPT J. LUKACHKO
NAVIGATOR CAPT L. ZIRKER
ACFT TYPE, MODEL NO TC 192
DATE 15 APR 1765
FROM MAFB
TO MAFB
VIA OW #4
ORGANIZATION T-40
TAKE OFF GROSS WT 44,000 #

TO	MSA	ALT	TEMP	WIND	IAS	TAS	GS	LEG DIST	LEG TIME	ACCUM TIME	FUEL FOR ACCUM TIME	ACCUM DIST	TC	DRIFT CORR	TH	VAR	MH	ETA ATA
WILLIAMS VORTAC	—	/	—	180/20	—	157	172	46	16			46	311	-6	305	-18	287	
UKIAH VORTAC	—	/	—	180/20	—	157	159	58	22	38		104	267	-7	262	-18	244	
40-00N 127-30W	68	120	+5	270/20	154	190	171	203	1:11	1:49		307	286	-2	284	-18½	265½	
39-22N 133-51W	20	120	+5	270/20	154	190	170	296	1:45	3:34		603	262	+1	263	-19	244	
41-00N 130-00W	20	130	+3	260/20	152	190	208	202	58	4:32		805	060	-2	058	-19	039	
UKIAH VORTAC	68	130	+3	260/20	152	190	207	330	1:36	6:08		1135	111	+3	114	-19	095	
MATHER VOR	68	130	+3	260/20	152	190	208	104	30	6:38		1239	104	+2½	106½	-18	087½	
				/														
				/														
				/														
				/														
				/														
				/														
				/														
TERMINAL ALTERNATE CASTLE AFB	—	13.0	+3	260/20	152	190	192	80	25				162	+6	168	-18	150	

TIME AND FUEL ANALYSIS

FUEL R. FACTOR 15.0 DENSITY		TIME	FUEL
1 ENROUTE		6:38	6050
2 TERMINAL ALTERNATE		:25	
3 (1+2)		7:03	6400
4 10% RESERVE		:42	600
5 (3+4)		7:45	7000
6 HOLDING		:45	
7 APPROACH & LANDING		:15	
8 PLANNED T O		8:45	7800
9 TAXI, RUNUP & T O			500
10 RAMP	PLANNED		8,300
	ACTUAL		9,000
11 ACTUAL T O			8,400
12 (11-8)+4 PRO RATA			1,200

CLEARANCE:

ATC CLRS DECA_ 69 TO MAP
VIA DIR ILA VT-FP: T~~AM~~ 12.0
CNTC DPC 121.1 — 318.2

Figure 24-8. Flight Plan (AF Form 21, Navigator's Log)

bottom with planned flying time from block 8 (8:45). Proceed vertically to the fuel consumed line and extract the required amount of fuel (7,800 lbs). Log this value in the fuel column of block 8 as shown in figure 24-8. Log the predetermined taxi, runup, and takeoff fuel in block 9 (500 lbs is used for the aircraft in this example). Add blocks 8 and 9 to obtain the planned ramp fuel (block 10).

Upon arrival at the aircraft, determine the actual amount of fuel on board (in this case 9,000 lbs), and log that value in the actual ramp section of block 10. Check the fuel gage again immediately after takeoff and log the amount in block 11 (8,400 lbs).

Pro rata fuel is the actual takeoff fuel minus the planned takeoff fuel, plus the ten percent reserve fuel. It is logged in block 12.

Range Control Graph. A range control graph, shown in figure 24-9 is prepared by the navigator. It portrays planned, maximum, and actual fuel consumption. It is used to flight plan fuel consumption and serves as an inflight worksheet for comparing actual and planned fuel consumption.

This range control graph is constructed with in-

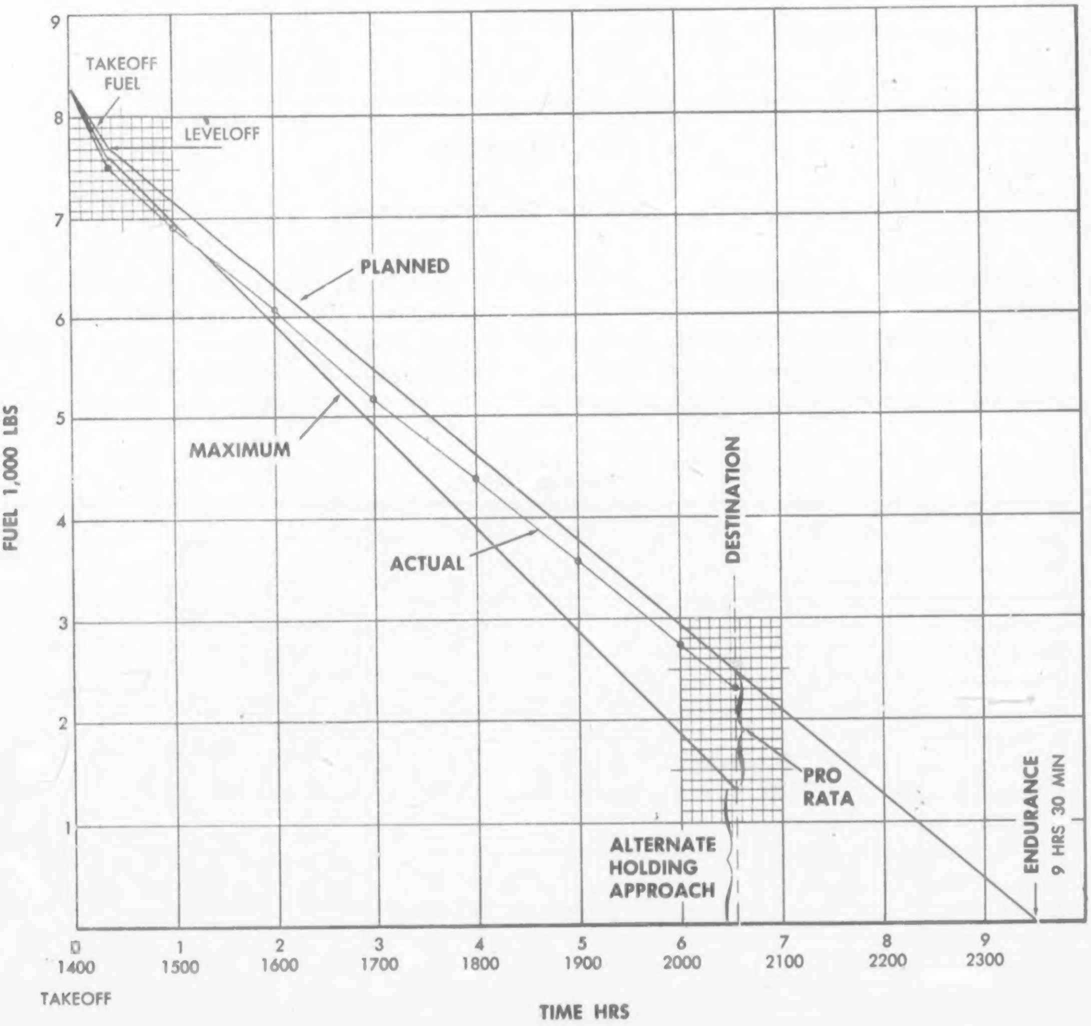


Figure 24-9. Range Control Graph

formation taken from the completed flight plan (figure 24-8) and the applicable fuel graph (figure 24-7). As shown in figure 24-9, fuel remaining (vertical) is plotted against time flown (horizontal). The bottom of the graph represents empty fuel tanks. Plot takeoff fuel on the left side of the graph and use it as the starting point for plotting the fuel consumption lines.

Draw the *planned* fuel consumption line through points representing the planned fuel remaining at takeoff, leveloff, and each hour after takeoff. This line is labeled PLANNED. Compute the fuel remaining at each point by subtracting planned fuel consumed, at each point, from the total takeoff fuel. Draw the planned fuel consumption line to the bottom of the graph to obtain the planned *endurance* (flying time until out of fuel).

The MAXIMUM fuel consumption line represents the highest fuel consumption possible to arrive at destination with sufficient fuel remaining for the alternate, holding, and approach and landing. Compute it by distributing the pro rata fuel (block 12 of figure 24-8) proportionately throughout the flight, using the formula:

$$\frac{\text{Pro Rata Fuel}}{\text{Total Time Enroute}} = \frac{\text{Difference in Max and Planned}}{\text{Time Enroute to Point}}$$

Example for leveloff:

$$\frac{1200\text{ lbs}}{6{:}33} = \frac{\text{Diff (66 lbs)}}{22\text{ min}}$$

Compute "Diff" for each point on the PLANNED line. Then plot each difference directly below the point for which it was computed. Thus, each point on the MAXIMUM line represents the minimum amount of fuel remaining for that time of the flight. Draw a vertical line through the total time enroute. Label this vertical line DESTINATION.

As the flight progresses, obtain fuel readings (fuel remaining) and plot on the graph for the time of the fuel reading. Draw a line through these points on the graph and label it ACTUAL. The trend of the ACTUAL line indicates whether the aircraft is following the planned fuel consumption schedule or not.

Equal Time Point

The equal time point (ETP) is a point along the route from which it takes the same amount of time to return to departure as it would to continue to destination. It is usually computed when planning long, overwater flights.

The ETP is not necessarily the midpoint in time from departure to destination. Its location is somewhere near the midpoint of the route, however, and it is dependent upon the wind factors.

A *wind factor* is a headwind or tailwind component which is computed by comparing the average groundspeed (GS) to the true airspeed (TAS). To do this, algebraically subtract the TAS from the GS. When the wind factor is a minus value (GS less than TAS), it is called a *head wind factor;* when it is a plus value (GS greater than TAS), it is a *tail wind factor.* When computing ETP, obtain a wind factor for each half of the route.

Use the following formula to compute a ETP:

$$\frac{\text{Total distance}}{GS_r + GS_c} = \frac{\text{ETP (in miles from departure)}}{GS_r}$$

Total distance is the number of nautical miles from departure to destination. Since ETP is most significant for the overwater portion of a flight, the ETP should be determined from coastal departure points and for alternate landing ponits. GS_r is the groundspeed to return to departure from the ETP. Compute it for the first half of the route by applying the wind factor with the sign reversed to the TAS. GS_c is the GS to continue from the ETP to destination. Determine it by applying the wind factor for the second half of the route to the TAS.

Using the flight plan shown in Figure 24-4, compute the distance to the ETP:

$$\frac{2305\text{ NM}}{510\text{k} + 450\text{k}} = \frac{\text{ETP (1224 NM)}}{510\text{k}}$$

Total distance is from Ukiah (coastal departure): 2402 − 97 = 2305. Compute the time to the ETP using the average GS on the first half of the route (410k) and the distance to the ETP (1224 NM). Thus, the time to the ETP for the flight shown in figure 24-4 is 2:59 from coastal departure.

Procedure Turn

A procedure turn is a turn begun before the aircraft reaches a turning point. By beginning the turn at a predetermined time and by turning a standard number of degrees per second, the aircraft will roll out on course to the next navigational check point. Consider the procedure turn tables

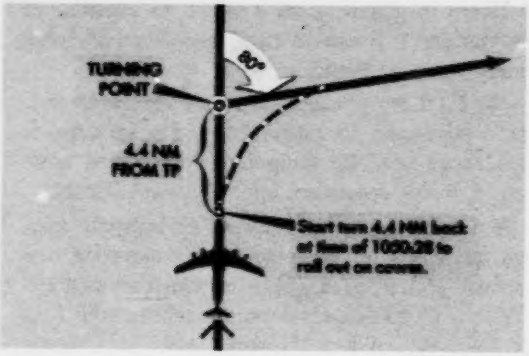

TURNING POINT
80°
4.4 NM FROM TP
Start turn 4.4 NM back at time of 1050:28 to roll out on course.

Figure 24-11. Procedure Turn

in figure 24-10A, B, C, and D. Along the top are the number of degrees of true heading change in 10° increments. On either side is groundspeed in 100-knot increments. There are tables for one-minute turns (6°/sec), two-minute turns (3°/sec), four-minute turns (1½°/sec) and eight-minute turns (3/4°/sec).

The tables allow procedure turn computations either by time or distance. The navigator may monitor the aircraft position until it is a certain distance back from the turning point, or he may subtract the amount of time (seconds) from the ETA to begin his turn. For example, a four-minute turn (1½°/sec) is desired for a true heading change of 80° at a true airspeed of 500 knots. Enter the four-minute procedure turn table (figure 24-10C) with groundspeed and true heading change. The distance back to begin the turn is 4.4 nautical miles. Then proceed vertically to the line marked Time Back, and read 32 seconds. In this example, ETA to the turning point is 1051, therefore, time to begin the turn is 1050:28. Continue further, and read the time saved in the turn (ten seconds). The bottom line contains the time required to complete the turn. The example above is shown in figure 24-11.

Summary

The flight plan provides a predetermined record of how a mission should progress. One of the navigator's most important tasks during any flight is the planning of required fuel and the monitoring of fuel consumption in flight. On long range, overwater flights, he may also be required to compute an equal time point. Therefore, the navigator must have a thorough understanding of these essential elements of mission planning.

A. ONE-MINUTE TURN (6°/SECOND)*

GROUNDSPEED (KNOTS)	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°
GROUND DISTANCE BACK TO START TURN (NM)												
100	—	—	.1	.1	.1	.2	.2	.2	.3	.3	.4	.5
200	—	.1	.1	.2	.2	.3	.4	.4	.5	.6	.8	.9
300	.1	.1	.2	.3	.4	.5	.6	.7	.8	1.0	1.2	1.4
400	.1	.2	.3	.4	.5	.6	.7	.9	1.1	1.3	1.5	1.8
500	.1	.2	.4	.5	.6	.8	.9	1.1	1.3	1.6	1.9	2.3
600	.1	.3	.4	.6	.7	.9	1.1	1.3	1.6	1.9	2.3	2.8
700	.2	.3	.5	.7	.9	1.1	1.3	1.5	1.9	2.2	2.7	3.2
800	.2	.4	.6	.8	1.0	1.2	1.5	1.8	2.1	2.5	3.1	3.7
900	.2	.4	.6	.9	1.1	1.4	1.7	2.0	2.4	2.9	3.5	4.1
1000	.2	.5	.7	1.0	1.2	1.5	1.9	2.2	2.7	3.2	3.8	4.6
TIME BACK (ETA ADJUST TO START TURN)	1"	2"	3"	4"	5"	6"	7"	8"	10"	11"	14"	17"
TIME SAVED IN TURN	—	—	—	—	1"	1"	2"	3"	4"	6"	9"	13"
TIME REQUIRED TO COMPLETE TURN	2"	3"	5"	7"	8"	10"	12"	13"	15"	17"	18"	20"

For radius of turn, extract from 90 column (double for turn diameter)

B. TWO-MINUTE TURN (3°/SECOND)

GROUNDSPEED (KNOTS)	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°
GROUND DISTANCE BACK TO START TURN (NM)												
100	—	.1	.1	.2	.2	.3	.4	.4	.5	.6	.8	.9
200	.1	.2	.3	.4	.5	.6	.7	.9	1.1	1.3	1.5	1.8
300	.1	.3	.4	.6	.7	.9	1.1	1.3	1.6	1.9	2.3	2.8
400	.2	.4	.6	.8	1.0	1.2	1.5	1.8	2.2	2.5	3.1	3.7
500	.2	.5	.7	1.0	1.2	1.5	1.9	2.2	2.7	3.2	3.8	4.6
600	.3	.6	.9	1.2	1.5	1.8	2.2	2.6	3.2	3.8	4.6	5.5
700	.3	.7	1.0	1.4	1.7	2.1	2.6	3.1	3.7	4.5	5.4	6.5
800	.4	.8	1.2	1.6	2.0	2.5	3.0	3.5	4.3	5.1	6.1	7.4
900	.4	.9	1.3	1.8	2.2	2.8	3.3	4.0	4.8	5.7	6.9	8.3
1000	.5	1.0	1.4	2.0	2.5	3.1	3.7	4.4	5.3	6.3	7.7	9.2
TIME BACK (ETA ADJUST TO START TURN)	2"	3"	5"	7"	9"	11"	13"	16"	19"	23"	27"	33"
TIME SAVED IN TURN	—	—	—	1"	1"	2"	3"	5"	8"	12"	18"	26"
TIME REQUIRED TO COMPLETE TURN	3"	7"	10"	13"	17"	20"	23"	27"	30"	33"	37"	40"

For radius of turn, extract from 90° column (double for turn diameter)

C. FOUR-MINUTE TURN (1½°/SECOND)

GROUNDSPEED (KNOTS)	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°
GROUND DISTANCE BACK TO START TURN (NM)												
100	.1	.2	.3	.4	.5	.6	.7	.9	1.1	1.3	1.5	1.8
200	.2	.4	.6	.8	1.0	1.2	1.5	1.8	2.1	2.5	3.1	3.7
300	.3	.6	.9	1.2	1.5	1.8	2.2	2.6	3.2	3.8	4.6	5.5
400	.4	.8	1.2	1.6	2.0	2.4	3.0	3.5	4.3	5.1	6.1	7.3
500	.5	1.0	1.5	2.0	2.5	3.0	3.7	4.4	5.3	6.3	7.7	9.2
600	.6	1.2	1.7	2.3	3.0	3.7	4.5	5.3	6.4	7.6	9.3	11.0
700	.7	1.4	2.0	2.7	3.4	4.3	5.2	6.2	7.4	8.9	10.7	12.9
800	.8	1.6	2.3	3.1	3.9	9.9	6.0	7.0	8.5	10.1	12.3	14.7
900	.9	1.8	2.6	3.5	4.4	5.5	6.7	7.9	9.6	11.4	13.8	16.6
1000	1.0	2.0	2.9	3.9	4.9	6.1	7.4	8.8	10.6	12.7	15.4	18.4
TIME BACK (ETA ADJUST TO START TURN)	3"	7"	10"	14"	18"	22"	27"	32"	38"	45"	55"	66"
TIME SAVED IN TURN	—	—	1"	2"	3"	5"	7"	10"	16"	24"	36"	52"
TIME REQUIRED TO COMPLETE TURN	7"	13"	20"	27"	33"	40"	47"	53"	60"	67"	73"	80"

For radius of turn, extract from 90° column (double for turn diameter)

D. EIGHT-MINUTE TURN (¾°/SECOND)

GROUNDSPEED (KNOTS)	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°
GROUND DISTANCE BACK TO START TURN (NM)												
100	.2	.4	.6	.8	1.0	1.2	1.5	1.8	2.1	2.5	3.1	3.7
200	.4	.8	1.2	1.6	2.0	2.4	2.9	3.5	4.3	5.1	6.1	7.4
300	.6	1.2	1.7	2.3	3.0	3.7	4.4	5.3	6.4	7.6	9.2	11.1
400	.8	1.6	2.3	3.1	3.9	4.9	5.8	7.0	8.5	10.2	12.3	14.7
500	1.0	2.0	2.9	3.9	4.9	6.1	7.3	8.8	10.7	12.7	15.4	18.4
600	1.2	2.3	3.5	4.7	5.9	7.3	8.7	10.6	12.8	15.2	18.4	22.0
700	1.3	2.7	4.0	5.5	6.9	8.6	10.2	12.3	15.0	17.8	21.5	25.7
800	1.5	3.1	4.6	6.3	7.9	9.8	11.7	14.1	17.0	20.3	24.6	29.4
900	1.7	3.5	5.2	7.0	8.9	11.0	13.1	15.9	19.2	22.8	27.6	33.0
1000	1.9	3.9	5.8	7.8	9.8	12.2	14.9	17.6	21.3	25.4	30.7	36.8
TIME BACK (ETA ADJUST TO START TURN)	7"	14"	20"	28"	36"	44"	54"	64"	76"	91"	109"	132"
TIME SAVED IN TURN	—	1"	2"	3"	6"	10"	14"	20"	32"	48"	72"	100"
TIME REQUIRED TO COMPLETE TURN	13"	27"	40"	53"	67"	80"	93"	107"	120"	133"	147"	160"

For radius of turn, extract from 90° column (double for turn diameter)

---

*NOTE: Use data from Table A to compute procedure turn information for non-charted turn rates. Multiply all distance and time increments extracted from this table by the number of minutes required to accomplish a 360° turn.

EXAMPLE: 12 minute turn (½°/sec), GS = 400 Knots, TH Change = 80°.
Ground distance back to start turn = .9 x 12 = 10.8 NM
Time back (ETA adjust to start turn) = 8" x 12 = 96" (1' 36")
Time saved in turn = 3" x 12 = 36"
Time required to complete turn = 13" x 12 = 156" (2' 36")
Radius of turn (90° column) = 1.1 x 12 = 13.2 NM
Diameter of turn = 2 x 13.2 = 26.4 NM

Figure 24-10. Procedure Turn Tables (Distance/Time Back)

CHAPTER 25

Inflight Procedures

This chapter describes in general terms procedures and techniques which assist the navigator with inflight problems. For example, he may be faced with situations in which he must gain or lose time to meet a controlled time of arrival. On long overwater flights he is required to maintain the proper forms and periodically to make weather and position reports. Instances also occur when electronic interference affects the reliability of navigational aids. In these cases, the navigator must rely upon his experience and judgment to interpret the information correctly from his observations and instruments. If weather or other conditions are unfavorable during the terminal phase of flight, he may be called upon to monitor the approach or to make an airborne radar approach to the terminal airport. An understanding of the procedures and techniques involved is therefore essential.

TAKEOFF AND CLIMB

Departure clearances are usually given in the form of an SID (standard instrument departure) or verbal clearance which identifies courses, navigational aids to proceed to, and altitudes during the climb. The SID is a published departure route for the airport which depicts the route to be followed during the climb and includes any altitude restrictions for certain check points. In the interests of flying safety adherence to the departure clearance is essential. It is the navigator's duty to monitor this clearance when received, to further monitor the progress of the aircraft during climb, and to insure that terrain clearance is maintained, particularly when a clearance other than an SID is given.

When ETAs are required during departure, the navigator provides them to the pilot. In this case, the ETAs are generally based on the best known groundspeed, which will be the flight plan groundspeed. In aircraft equipped with Doppler radar, the navigator can use actual groundspeed rather than flight planned groundspeed. When nearing cruising altitude, the navigator should also compute an indicated airspeed for the pilot to maintain during that portion of the flight.

CRUISE

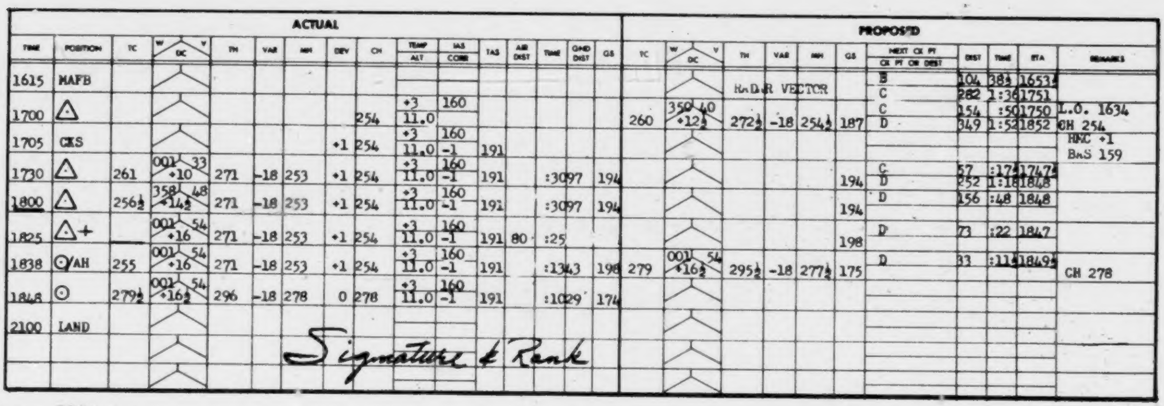
The duties of the navigator in flight are many and varied. While his primary duty is to monitor and direct the progress of the aircraft, he must meet many associated requirements such as completing the log, filling out forms, working controlled ETAs, and analyzing the information received from his navigation equipment.

Navigator's Log (AF Form 21)

The navigator's log is usually the only record of the aircraft actual position at any given time during the flight. For this reason it must be accurate and complete.

Not all organizations use the same log procedures; however, the basic log requirements remain the same. Log procedures used in dead reckoning and map reading, as well as procedures for computation of celestial, pressure differential, radar and Loran information are covered in previous chapters.

A typical completed log (AF Form 21, Navigator's Log) using several types of navigation methods is illustrated in figure 25-1. Each entry is self-explanatory. On the back of this log are computation records for various types of navigation. There are sections for celestial and pressure differential heading computations, and columns for



ACTUAL															
TIME	POSITION	TC	W/V DC	TH	VAR	MH	DEV	CH	TEMP ALT	IAS CORR	TAS	AIR DIST	TIME	GND DIST	GS
1615	MAFB														
1700	△							254	+3 11.0	160					
1705	CKS						+1	254	+3 11.0	160 -1	191				
1730	△	261	001/33 +10	271	-18	253	+1	254	+3 11.0	160 -1	191		:30	97	194
1800	△	256½	358/48 +14½	271	-18	253	+1	254	+3 11.0	160 -1	191		:30	97	194
1825	△+		001/54 +16	271	-18	253	+1	254	+3 11.0	160 -1	191	80	:25		
1838	⊙/AH	255	001/54 +16	271	-18	253	+1	254	+3 11.0	160 -1	191		:13	43	198
1848	⊙	279½	001/54 +16½	296	-18	278	0	278	+3 11.0	160 -1	191		:10	29	174
2100	LAND														

Signature & Rank

PROPOSED										
(TIME)	TC	W/V DC	TH	VAR	MH	GS	NEXT CK PT CK PT OR DEST	DIST	TIME	ETA	REMARKS
1615			RADAR VECTOR				B C	104 282	38½ 1:36	1653½ 1751	
1700	260	350/40 +12½	272½	-18	254½	187	C D	154 349	:50 1:52	1750 1852	L.O. 1634 CH 254
1705											HMC +1 BAS 159
1730						194	C D	57 252	:17½ 1:18	1747½ 1848	
1800						194	D	156	:48	1848	
1825						198	D	73	:22	1847	
1838	279	001/54 +16½	295½	-18	277½	175	D	33	:11½	1849½	CH 278

AF FORM MAY 65 21

Figure 25-1. Sample Log

$\frac{D_2-D_1}{Y}=\frac{BDCA}{1}$			$\frac{ZN}{K}=\frac{D_2-D_1}{ETAS}$		"D"	COMPUTATION	TIME
TA	18450	18425	18455			▨	
–PA	18200	18175	18205				
DIFF	+250	+250	+250		+250		1840
TA	18450	18450	18460	PLOP →		$\frac{+6.0}{39.25}=\frac{+33}{188}$	
–PA	18175	18175	18160				
DIFF	+275	+275	+300		+283		1910
TA	18470	18475	18475	BDCA (ZN) →		$\frac{+14}{39}=\frac{+77}{188}$ $\frac{+14}{83}=\frac{+9\frac{1}{2}}{57.3}$	
–PA	18110	18115	18155				
DIFF	+360	+360	+360		+360		1940
TA	18490	18485	18495	BDCA (Y) →		$\frac{+70}{8.27}=\frac{+8\frac{1}{2}^{\circ}}{1}$	
–PA	18060	18065	18055				
DIFF	+430	+420	+440		+430		2010

Figure 25-2. Sample Pressure Computation

loran, radio, radar/map reading, and consol fix information. Completed samples of these computations are shown in figures 25-2 through 25-5.

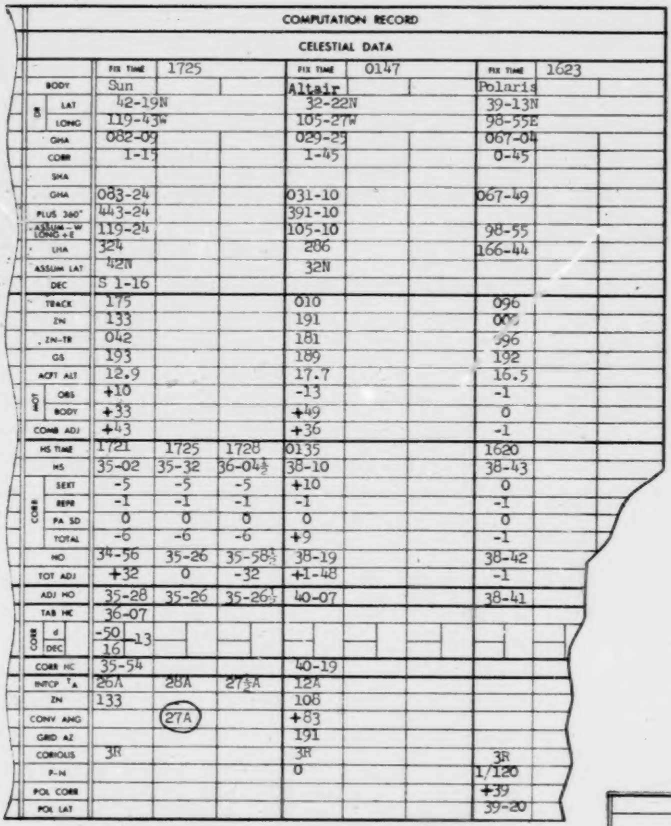
Controlled Time of Arrival

On routine flights, destination does not have to be reached at any particular time. The navigator merely has an ETA ready for destination at all times, based on the latest and best information.

However, on occasion, accurate timing is essential to the success of the mission. In a refueling operation or in any form of rendezvous, each aircraft must arrive on schedule. Even after joining, it may be necessary that the formation arrive over a given point at a specified time. A single aircraft may be ordered to be at a destination or a turning point at an exact time. In each of these situations, the procedure used is called *controlled time of arrival.*

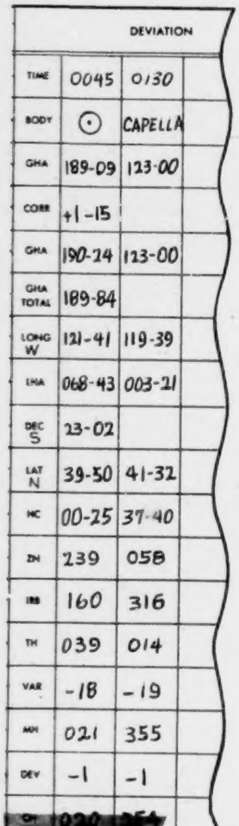
The time of arrival at a destination or target depends on three factors: (1) time of departure, (2) groundspeed, and (3) distance to fly. Time of arrival is controlled by varying one or more of these factors within certain limits. It is easy to lose time in flight, but is difficult to gain time. This is particularly true when dealing with large complex formations composed of different types of aircraft. The planning of a flight in which accurate time is essential should include some means of gaining time; for example, planning several navigation legs which can be shortened in flight to decrease the distance.

LOSING TIME. If an aircraft must reach a given



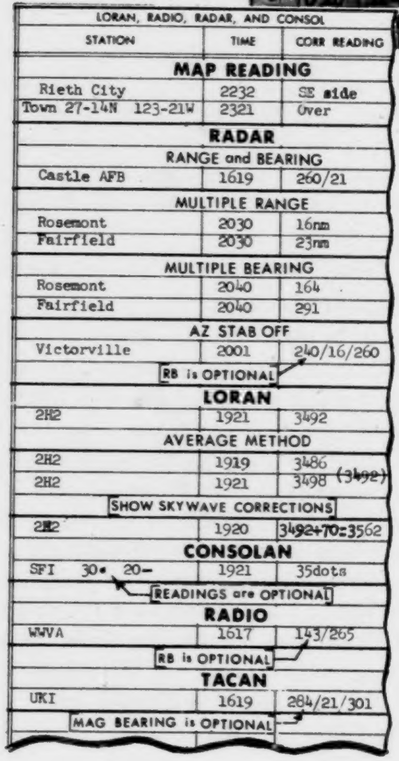
COMPUTATION RECORD									
CELESTIAL DATA									
	FIX TIME 1725			FIX TIME 0147			FIX TIME 1623		
BODY	Sun			Altair			Polaris		
LAT	42-19N			32-22N			39-13N		
LONG	119-43W			105-27W			98-55E		
GHA	082-09			029-25			067-04		
CORR	1-15			1-45			0-45		
SHA									
GHA	083-24			031-10			067-49		
PLUS 360°	443-24			391-10					
ASSUM −W LONG +E	119-24			105-10			98-55		
LHA	324			286			166-44		
ASSUM LAT	42N			32N					
DEC	S 1-16								
TRACK	175			010			096		
ZN	133			191			000		
ZN-TR	042			181			096		
GS	193			189			192		
ACFT ALT	12.9			17.7			16.5		
OBS	+10			-13			-1		
BODY	+33			+49			0		
COMB ADJ	+43			+36			-1		
HS TIME	1721	1725	1728	0135			1620		
HS	35-02	35-32	36-04½	38-10			38-43		
CORR SEXT	-5	-5	-5	+10			0		
REFR	-1	-1	-1	-1			-1		
PA SD	0	0	0	0			0		
TOTAL	-6	-6	-6	+9			-1		
HO	34-56	35-26	35-58½	38-19			38-42		
TOT ADJ	+32	0	-32	+1-48			-1		
ADJ HO	35-28	35-26	35-26½	40-07			38-41		
TAB HC	36-07								
CORR d	-50 -13								
DEC	16								
CORR HC	35-54			40-19					
INTCP ^T_A	26A	28A	27½A	12A					
ZN	133			108					
CONV ANG		27A		+83					
GRID AZ				191					
CORIOLIS	3R			3R			3R		
P-N				0			1/120		
POL CORR							+39		
POL LAT							39-20		

Figure 25-3. Sample Celestial Precomputations



DEVIATION			
TIME	0045	0130	
BODY	☉	CAPELLA	
GHA	189-09	123-00	
CORR	+1-15		
GHA	190-24	123-00	
GHA TOTAL	189-84		
LONG W	121-41	119-39	
LHA	068-43	003-21	
DEC S	23-02		
LAT N	39-50	41-32	
HC	00-25	37-40	
ZN	239	058	
RB	160	316	
TH	039	014	
VAR	-18	-19	
MH	021	355	
DEV	-1	-1	
CH	020	354	

Figure 25-4. Deviation



LORAN, RADIO, RADAR, AND CONSOL		
STATION	TIME	CORR READING
MAP READING		
Rieth City	2232	SE side
Town 27-14N 123-21W	2321	Over
RADAR		
RANGE and BEARING		
Castle AFB	1619	260/21
MULTIPLE RANGE		
Rosemont	2030	16nm
Fairfield	2030	23nm
MULTIPLE BEARING		
Rosemont	2040	164
Fairfield	2040	291
AZ STAB OFF		
Victorville	2001	240/16/260
RB is OPTIONAL		
LORAN		
2H2	1921	3492
AVERAGE METHOD		
2H2	1919	3486
2H2	1921	3498 (3492)
SHOW SKYWAVE CORRECTIONS		
2H2	1920	3492+70=3562
CONSOLAN		
SFI 30• 20–	1921	35dots
READINGS are OPTIONAL		
RADIO		
WWVA	1617	143/265
RB is OPTIONAL		
TACAN		
UKI	1619	284/21/301
MAG BEARING is OPTIONAL		

Figure 25-5. Sample LOP/Fix Substantiation Record

control point at a certain time, the best method is to fix the departure time to insure an early arrival, since unpredicted wind changes or tactical maneuvers may cause a loss in planned flight time.

If necessary, any of several simple methods can be used to lose time in order to meet a controlled time of arrival. These are S-turns, 360° turns, double drifts, 60° turns, and reducing airspeed. The most frequently used method is reducing airspeed.

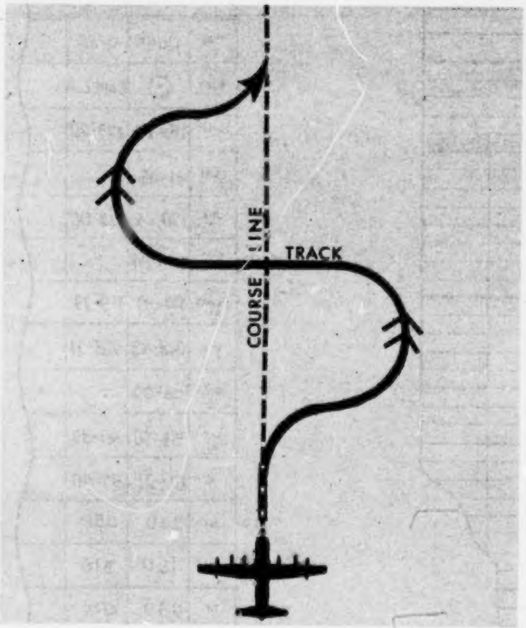


Figure 25-6. S-Turn

S-Turn. Figure 25-6 illustrates the S-turn maneuver. It is accomplished by a 90° turn from the original heading, followed by an immediate 180° turn from the new heading in the direction of destination straight and level for one minute to cross course, a 180° turn in the direction of destination to return to course, and then a 90° turn to the initial on-course heading. If 1½° per second turns are used exclusively, three minutes are lost per S-turn.

360° Turns. By using the aircraft turn-and-bank indicator, a standard turn of a given time duration can be made. If a 360° turn is made at a rate of 1½° per second, four minutes are lost in the turn. If a rate of 3° per second is used, the turn takes two minutes to complete.

Double Drift. This is a familiar maneuver to the navigator, consisting of a 45° turn from the on-course heading straight and level for 1½ minutes, a 90° turn back toward course straight and level for 1½ minutes, finally, a 45° turn back to the original heading. The time lost equals one minute. If an additional two minutes are flown per leg, another one minute is lost. In this maneuver a turn rate of 3° per second is normally used.

60° Turn Method. This is similar to a double drift except that more time can be conveniently lost. The method prescribes a 60° turn from the on-course heading, a 120° turn toward course, and a final turn to the original on course heading. This forms an equilateral triangle with the course, and the distance flown on each leg equals the equivalent course distance forming the third side of the triangle. The time flown on each leg equals the time lost on course; thus, if each leg is flown for twelve minutes, the on-course time lost should be 12 minutes. The turns, however, consume some time. One minute is lost in the three turns in a normal 1½° per second turn. For example, if twelve minutes must be lost, each leg is flown for 11 minutes; the twelfth minute is lost in the turns.

MAXIMUM TIME TO LOSE. The methods previously described are commonly used if only a few minutes must be lost. If a considerable amount of time is to be lost, it is better to increase the distance by flying an angular course. Two methods are most commonly used: the arc method and the perpendicular bisector method. Both methods make use of *airplot* to determine the headings necessary to bring the aircraft to the desired point at the required time.

Arc Method. Consider the following example in figure 25-7. An aircraft is proceeding along a true course of 024° at a groundspeed of 220 knots. The true heading is 033°, the TAS is 240 knots and the wind is 090°/40k. At 1030 the distance to fly to control point *B* is 375 nautical miles; the aircraft is to reach this control point at 1230.

At the present groundspeed, only 1 hour and 42 minutes is required to reach point *B* and the aircraft will arrive 18 minutes early. The problem is to increase the distance to fly so that, at the present airspeed, the additional 18 minutes will be consumed. The solution is as follows:

1. From a fix position at 1030, airplot ahead for sufficient time to solve the problem (10 minutes).
2. Plot a wind vector into destination representing the wind effect for 2 hours (1030 to 1230), or 80 NM. The tail of the wind vector is the air position for the control time (1230).
3. To arrive at the 1230 air position on time, flying 240 TAS, the distance must be increased. The distance is increased by establishing two navigation legs. Each leg is flown one-half of the remaining time $\left(\frac{1:50}{2} = 55 \text{ min}\right)$. From the 1230 air position and the 1040 air position, swing arcs

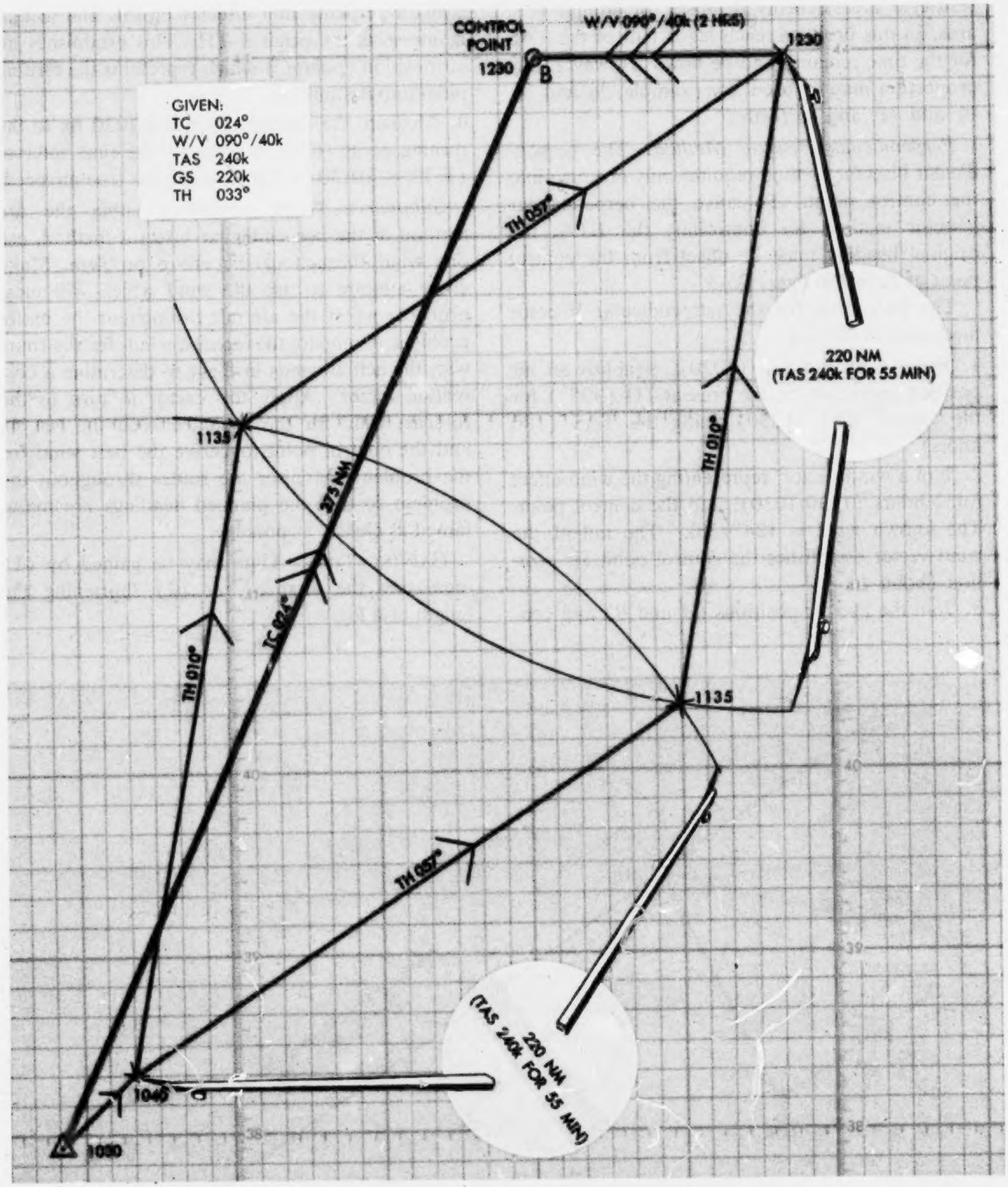

CONTROL POINT
1230
B
W/V 090°/40k (2 HRS)
1230
GIVEN:
TC 024°
W/V 090°/40k
TAS 240k
GS 220k
TH 033°
TH 057°
220 NM
(TAS 240k FOR 55 MIN)
TH 010°
1135
275 NM
TC 024°
TH 010°
1135
TH 057°
220 NM
(TAS 240k FOR 55 MIN)
1040
1030

Figure 25-7. Arc Method

with a radius 220 miles (55 min of TAS) intersecting at two possible turning points (1135 air positions), which fall one on each side of the original course. Measure the directions of the lines joining the 1040 air position, the 1135 air position, and the 1230 air position. These are the true headings to be flown. The decision to fly right or left of the original course may be dictated by restricted areas, enemy defenses, or similar hazards. In this problem, each leg is half of the TAS for the time remaining to be flown. However, any proportion may be used; for example, ⅓ and ⅔, ¼ and ¾, and so forth.

Perpendicular Bisector Method. The perpendicular bisector method requires only one turn into the control point. To solve the perpendicular bisector method for controlling the ETA, the original heading must be offset from the control point as shown in figure 25-8.

The procedure for the perpendicular bisector method is as follows:

1. From a fix position (1030), establish an air position (point *A*) on the present TH (305°) for the control time (1230) using the TAS (180 knots).
2. Plot a wind vector, representing the wind effect for 2 hours (1230-1030), into the control point. The known wind is 124°/33k. The tail of the wind vector establishes the control point air position (point *B*).
3. Join the two air positions (*A* and *B*) and construct a perpendicular bisector on this line so that it intersects the original TH. This establishes an air position (point *C*) which represents the turning point into destination.
4. Measure the distance from the 1030 fix to the turning point (*C*) and compute the time interval (1:30 + 10:30 = 1200) using the true airspeed.

Summary. When employing either the arc method or the perpendicular bisector method, use one wind throughout the entire problem. Make every attempt to use the wind which will most probably affect the aircraft throughout the entire problem. Compare the forecast winds for the route with the actual winds in flight to determine a correction factor. Apply this factor in turn to the forecast wind for the route between the last fix and the control point to derive the best wind for the problem. Monitor the routes throughout the problem so that the planned headings are maintained as closely as possible.

Gaining Time. Time may be gained by (1) increasing the airspeed, or (2) shortening the length of a leg.

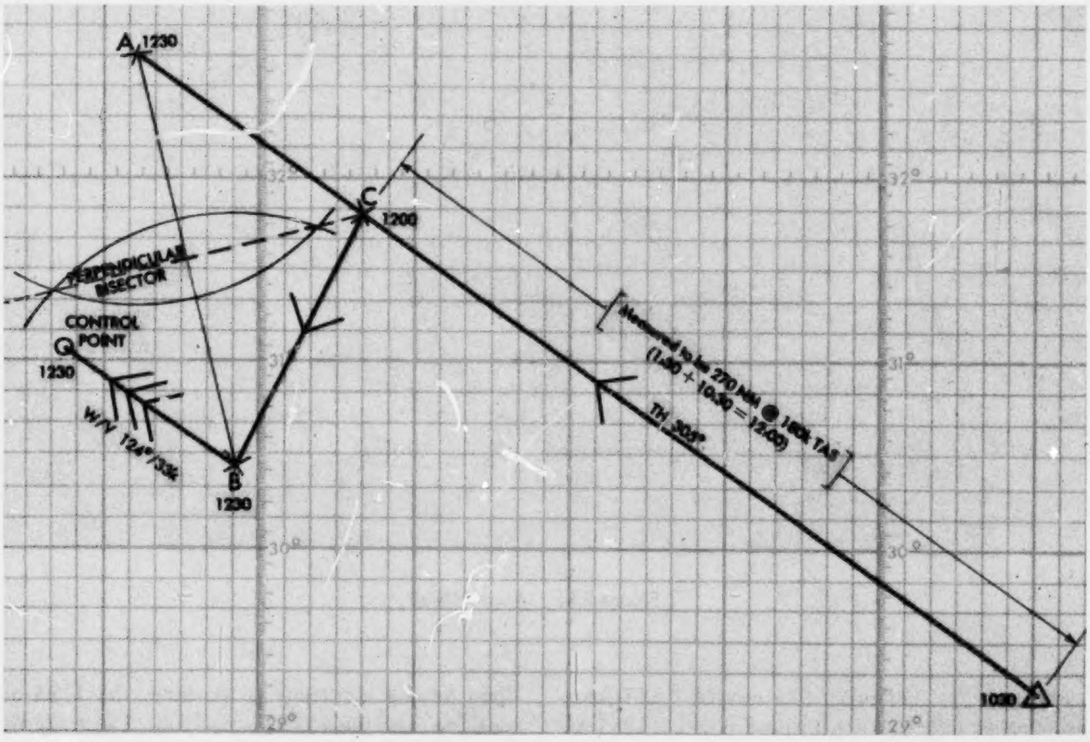


Figure 25-8. Perpendicular Bisector Method

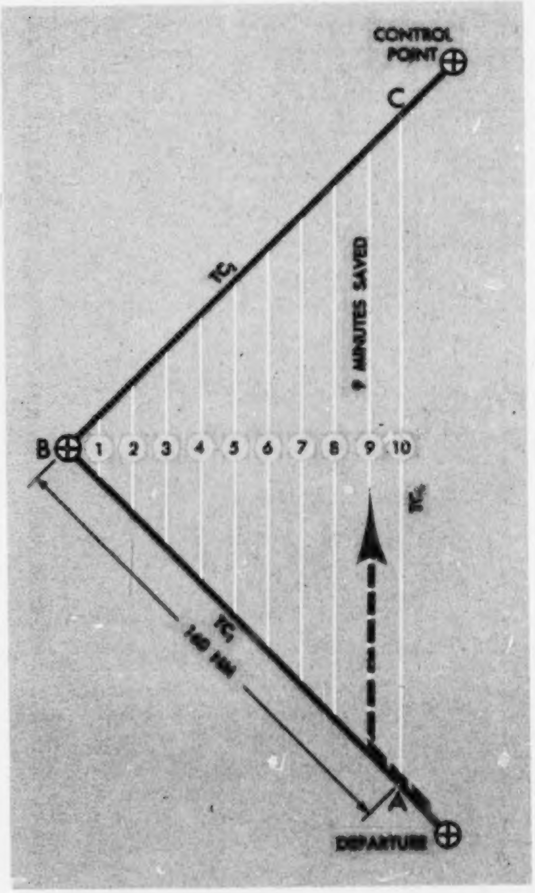


Figure 25-9. Cutting the Corner to Gain Time

Increasing the Airspeed. Increasing the airspeed will gain time only in limited amounts. To determine what true airspeed must be maintained to reach a given point at a given time, work the ETA problem backwards. By knowing the distance and the time to go, the groundspeed to be made good can be computed. With the known groundspeed and wind, use the wind side of the computer to find the true airspeed necessary to maintain this groundspeed.

Cutting the Corners. A simpler method of gaining time, however, is to plan the flight so that corners may be cut if necessary to arrive over a given control point at the specified time. This standby method is computed on the ground and saves computations in the air. The procedure is illustrated in figure 25-9 and is accomplished as follows:

1. Construct a point *A* on TC_1 back from the turning point *B* an arbitrary distance; for example, 160 miles, as shown in the accompanying sketch.
2. On TC_2 construct point *C* also 160 miles from point *B*.
3. Connect points *A* and *C*. Determine the time to fly from *A* to *C* directly and the time to fly from *A* to *C* via *B*. The difference in time is the amount saved (10 minutes).
4. Divide the arbitrary distance, 160 miles, by the amount of time saved.

$$\frac{160}{10} = 16$$

5. Construct parallel TC_3's every 16 miles along *A* to *B*. These intersections become potential turns to save smaller amounts of time. Thus, a course drawn 144 miles from *B* between TC_1 and TC_2 will save 9 minutes of time and so forth.

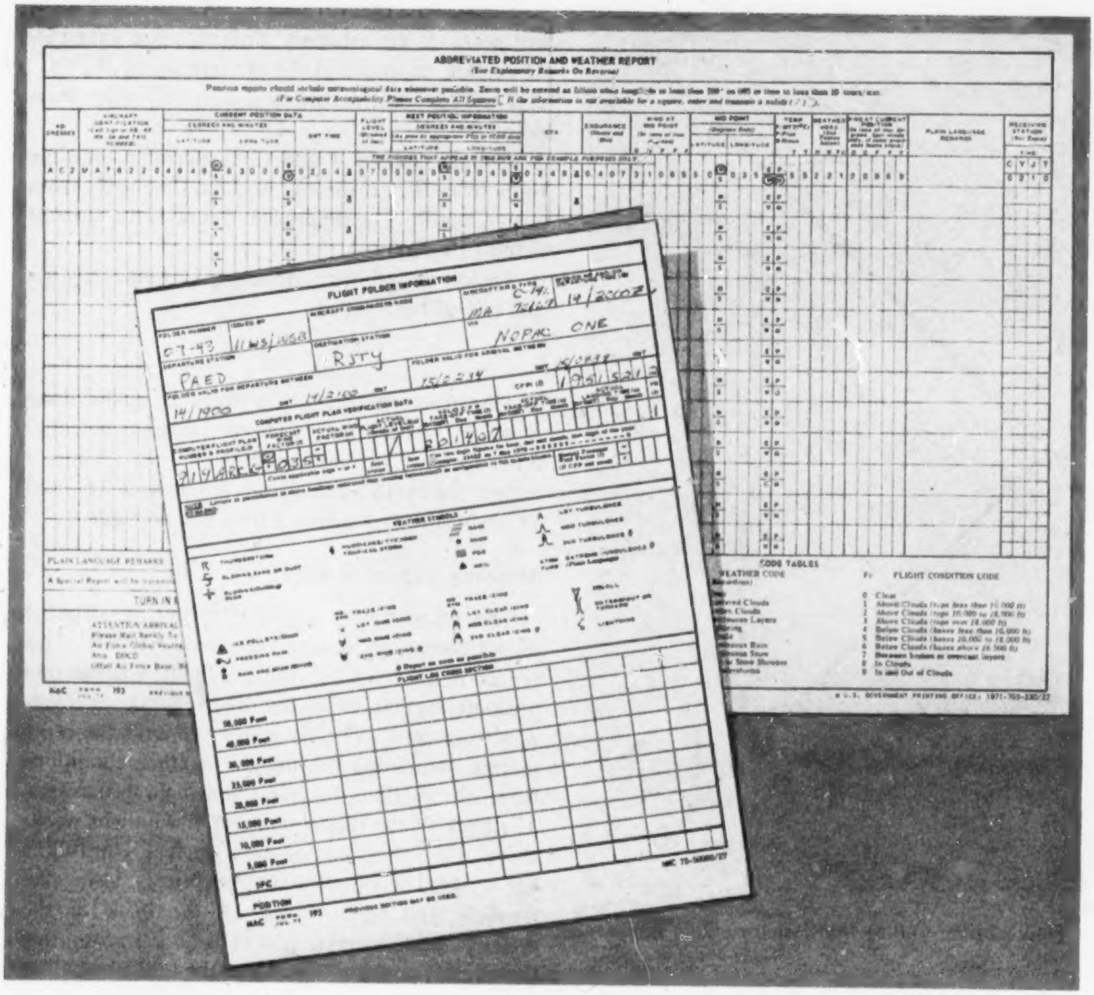
Airborne Report (AIREP)

The navigator is responsible for the airborne report commonly referred to as an AIREP. This report is used for recording inflight weather and position reports primarily when flying on overwater missions. The navigator prepares the cross section containing the inflight weather conditions from observations taken as the flight progresses. The back of the report contains the inflight worksheet. One transmission to a surface controlling agency can accomplish two purposes. Using the symbols and terms given on the back of the AIREP, the information is coded for transmitting the aircraft position report and the inflight weather report. This coding makes possible the use of computers to speed the most current weather information to the using agencies. It is therefore possible for a flight departing for the area from which an AIREP is being transmitted, to be given the inflight weather from that AIREP.

As a rule, this weather is very accurate since it is actual inflight information. A typical AIREP is illustrated in figure 25-10.

Electronic Interference

Electronic interference falls into two categories: intentional and non-intentional. Both affect the reliability of the information obtained from the navigator's instruments. The greater danger comes from intentional interference since it constitutes an attempt to lead the aircrew astray. Non-intentional interference might be caused by anything from a



ABBREVIATED POSITION AND WEATHER REPORT

FLIGHT FOLDER INFORMATION

07-43

RJTY

PAED

14/1900

NOPAC ONE

C-141

CODE TABLES

FLIGHT CONDITION CODE

0 Clear
1 Above Clouds (tops less than 10,000 ft)
2 Above Clouds (tops 10,000 to 18,000 ft)
3 Above Clouds (tops over 18,000 ft)
4 Below Clouds (bases less than 10,000 ft)
5 Below Clouds (bases 10,000 to 18,000 ft)
6 Below Clouds (bases above 18,000 ft)
7 Between broken or overcast layers
8 In Clouds
9 In and Out of Clouds

FLIGHT LOG CODE SECTION

50,000 Feet
40,000 Feet
30,000 Feet
25,000 Feet
20,000 Feet
15,000 Feet
10,000 Feet
5,000 Feet
SFC
POSITION

Figure 25-10. A Typical AIREP

thunderstorm to electrical equipment aboard the aircraft.

Interference comes in many forms. Among these are audible noise, erroneous bearings from radio facilities, and false radarscope presentations.

The most important thing is that the navigator must recognize the fact that his equipment may be giving him incorrect information. *Good dead reckoning* and a good estimate of the correct information help him to detect incorrect information from his instruments.

INTENTIONAL INTERFERENCE. Generally the transport aircrew member contends with two types of countermeasures. These are jamming and deception. The navigator may experience them simultaneously.

Jamming. Jamming is the deliberate radiation, reradiation, or reflection of electromagnetic energy with the object of impairing the use of electronic devices, equipments, or systems. This decreases the ability of the equipment to accomplish its designed purpose or function. If jamming is strong enough, it can render the equipment entirely useless. In figure 25-11 several different intensities of radar jamming are shown.

Another form of jamming is mechanical, usually in the form of chaff or other radar reflectors. These materials may be dropped from aircraft or positioned on the ground to obscure targets or to

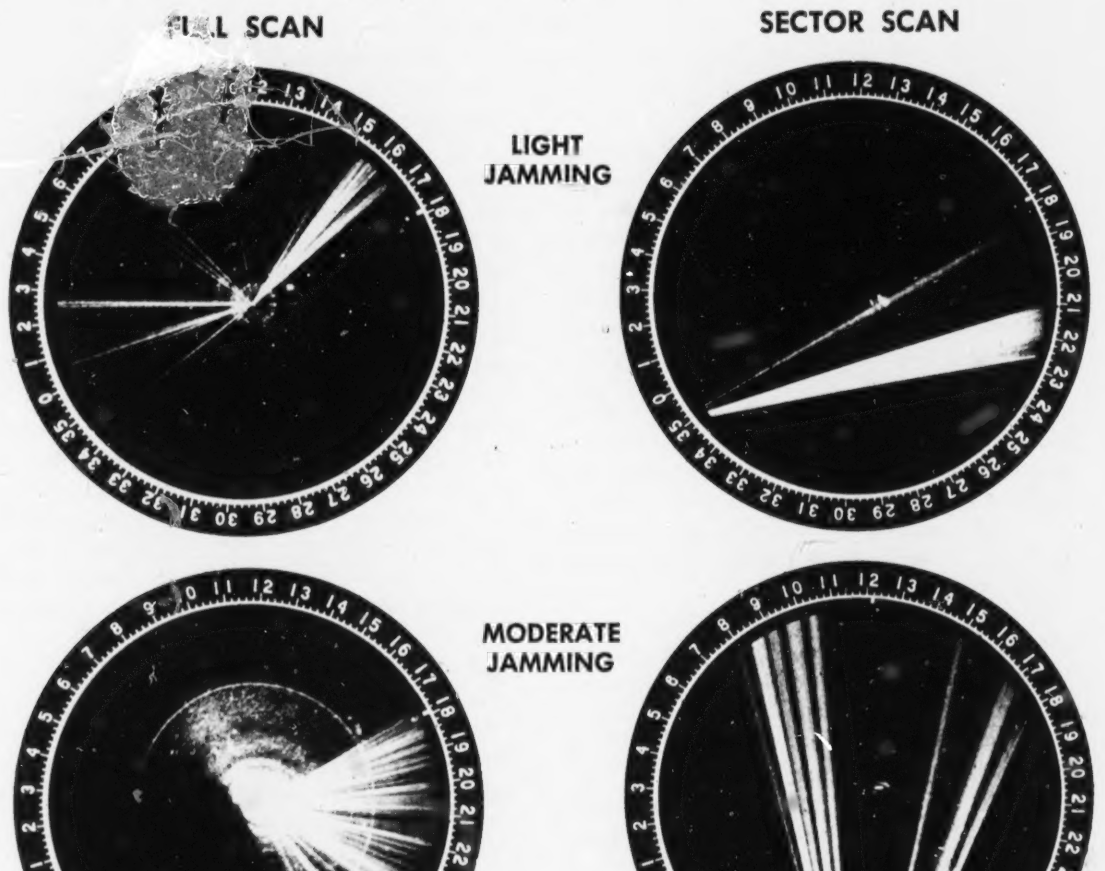

FULL SCAN
SECTOR SCAN
LIGHT JAMMING
MODERATE JAMMING
HEAVY JAMMING

Figure 25-11. Radarscope Jamming

change their appearance on a radarscope. Chaff dropped from an aircraft may appear as a single radar return or many returns, or it may totally obscure an entire area.

Deception. Deception, another type of intentional interference, can be more dangerous than jamming. It is intended to mislead or confuse the crew by causing the airborne electronic equipment to provide erroneous information. This can be done electronically or mechanically through the use of falsely positioned beacons (meaconing) or the use of radar reflecting devices to change the radar appearance of geographic or cultural features. The speed of present operational aircraft greatly reduces the effectiveness of meaconing and reflective deception because of the limited area which they affect. These techniques, however, can be very effective in preventing close tolerance aircraft tracking and in making specific target identification difficult.

Intrusion. Intrusion is another form of deception used primarily in communication systems. This again is the insertion of false material to confuse the crew by obscuring the authentic information. Intrusion can be accomplished by several methods. Two of the most common are:

1. Use of a Linguist. A hostile linguist, impersonating a GCA operator or ground radar controller, could direct an unsuspecting aircraft off course or to an unsuccessful landing.
2. Use of a Recording. The enemy can record a well known, friendly, GCA operator or ground radar controller, and play the recording back at a later time when the erroneous headings or altitudes would be hazardous to an aircrew.

General. A clever enemy can confuse or interfere with virtually all electronic equipment. An aircrew operating in a hostile environment should remember that, at any time, any or all electronic equipment can be degraded by interference. Good dead reckoning and the use of several aids to crosscheck positioning information are the best means of recognizing and countering deception. When jamming or deception is experienced, the incident must be reported to insure that crews on later flights are warned to take necessary precautions. Interference reports should be made in accordance with the provisions of AFR 55-3.

NON-INTENTIONAL INTERFERENCE. Non-intentional interference is either natural or man-made. Either type can seriously impair the use of airborne electronic equipment.

Natural Interference. Certain natural phenomena can generate sufficient electromagnetic energy to limit the usefulness of radio, loran, and other electronic aids. Natural interference is classified as atmospheric noise or universal noise.

- Atmospheric noise. Atmospheric noise is caused by precipitation, lightning, and similar phenomena. Precipitation causes an increase in the receiver noise level and decreases the effectiveness of the receiver. Lightning causes loud, short bursts of sharp static.
- Universal noise. This type of interference has either galactic or solar origins. Galactic noise is usually weak and has little effect on communications. Solar noise can be very intense and damaging to communications. It is caused by sunspots and can be predicted in advance. Solar noise fluctuates and is usually found in the 10 mHz to 200 mHz range.

MAN-MADE INTERFERENCE. Man-made noise comes from many sources, many of them on the aircraft. Reciprocating engines are notorious offenders because spark plugs and other high-voltage parts of the ignition system radiate interference which changes with engine rpm. Voltage regulator points and relays also create noise, but the frequency is much lower.

At low altitudes over heavily populated areas, interference from ground-based equipment may be encountered. This comes from power lines, neon lighting, and similar equipment. This interference affects amplitude modulated (AM) radio equipment more than other electrical equipment.

WEATHER AND OTHER EFFECTS. Every aircrew member knows the obvious ways in which weather affects the success of a mission. But weather can also influence missions in many subtle ways, some of which are explained below.

Uunusual Range. Under certain weather conditions, both low and high frequency radio waves travel surprisingly long distances, even from low-power transmitters. Whenever a radio transmits, there is no guarantee that the signal will not be received by hostile agencies.

Ducting. Layers of air having different temperatures can form a "duct" which traps electromagnetic waves and channels them for great distances. Under these conditions a radar set might "see" targets many times more distant than the normal range.

Moisture Absorption. Water vapor can absorb high-frequency electromagnetic energy, and thereby greatly shorten usable range. This is particularly true when infra-red frequencies are involved.

Magnetic Storms. In the polar regions, wandering "magnetic storms" can severely limit the range of the most powerful radio equipment. Point-to-point and scatter-type long-range communications can be nullified, while air-to-ground systems, usually capable of several hundred miles of range, can be limited to as few as one or two miles. These storms are unpredictable and can make an electronically-controlled approach very hazardous.

DESCENT

Standard Approaches

The descent portion of the flight is similar to the climb portion. Instrument approach plates are published for almost all airfields of any significance in the world. These are similar to the SID that is used for departure. The published approaches are normally flight checked for safety of flight; if not, they are appropriately annotated. The navigator must make certain that the route affords adequate terrain clearance whether it is a published let down or a verbal clearance given by the approach control. Because of congested air traffic, approaches must be followed precisely. The navigator should monitor the aircraft position and altitude during descent and advise the pilot of any deviations.

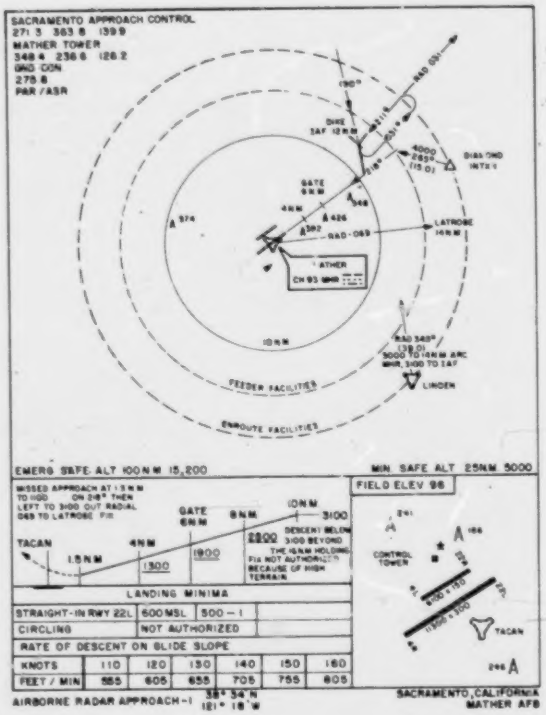

SACRAMENTO APPROACH CONTROL
271.3 363.8 139.9
MATHER TOWER
348.4 236.6 126.2
GND CON
275.8
PAR / ASR
190°
RAD 031
DIKE
IAF 12NM
211°
031°
4000
265°
(15.0)
DIAMOND
INTX
216°
GATE
6NM
4NM
A 374
A 426
A 382
A 346
RAD-069
LATROBE
14NM
ATHER
CH 93 MHR
10NM
RAD 340°
(38.0)
5000 TO 14NM ARC
MHR, 3100 TO IAF
LINDEN
FEEDER FACILITIES
ENROUTE FACILITIES
EMERG SAFE ALT 100NM 15,200
MIN SAFE ALT 25NM 5000
MISSED APPROACH AT 1.5NM
TO 1100 ON 216° THEN
LEFT TO 3100 OUT RADIAL
069 TO LATROBE FIX
TACAN
1.5NM
4NM
1300
GATE
6NM
1900
8NM
2500
10NM
3100
DESCENT BELOW
3100 BEYOND
THE 16NM HOLDING
FIX NOT AUTHORIZED
BECAUSE OF HIGH
TERRAIN
LANDING MINIMA
STRAIGHT-IN RWY 22L 600MSL 500 – 1
CIRCLING NOT AUTHORIZED
RATE OF DESCENT ON GLIDE SLOPE
KNOTS 110 120 130 140 150 160
FEET / MIN 555 605 655 705 755 805
FIELD ELEV 96
CONTROL
TOWER
TACAN
AIRBORNE RADAR APPROACH-1
38° 34' N
121° 18' W
SACRAMENTO, CALIFORNIA
MATHER AFB

Figure 25-12. Sample ARA Procedures

Airborne Radar Approach (ARA)

An additional means of approach to the terminal airfield available to the aircrew is the airborne radar approach (ARA). The ARA is an emergency procedure used when other approaches are not available. When using this means, the pilot receives all directions and altitudes from the navigator. ARA let down plates are published for some airfields. A typical ARA approach is shown in figure 25-12. Where an ARA let down plate has not been published, the navigator may plan one himself. The navigator computes the absolute altitude above field elevation for each one-mile increment from touchdown point on final approach. To do this, he uses the rate of descent and the final approach speed for his aircraft. A typical glide slope computed by the navigator is shown in figure 25-13. The field elevation must be added to each of the altitudes to produce the correct altitudes for the pilot to fly. This will be the true altitude read on the pressure altimeter (the local altimeter setting in the Kollsman window).

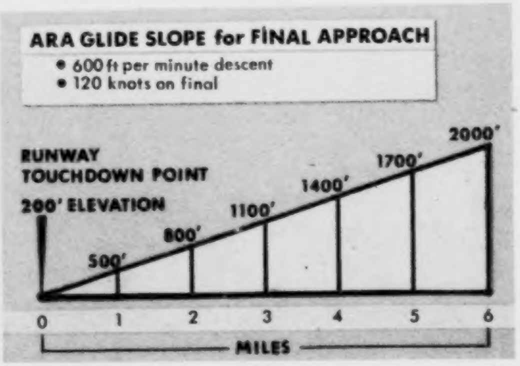


Figure 25-13. Typical Glide Slope Computed by Navigator

The navigator may be directed by ground control to the point from which he plans to begin the ARA or he may direct the aircraft to this point himself. In either case, once on the final approach, the navigator is directing the aircraft. To do this, he must keep the pilot informed of the altitudes and headings to the runway. After the aircraft has landed, the navigator's duties terminate except for completing the navigation checklists and required reports.

CHAPTER 26

Low Level Navigation

FUNDAMENTALS

The main reasons for conducting low level operations are to gain the element of surprise, to avoid detection and interception, and to minimize the effect of enemy defenses. In addition, certain types of operations such as para-drops and aerial re-supply missions demand a low level capability. The problem of performing accurate navigation at low levels differs considerably from that at higher altitudes. Low level navigation requires comprehensive flight planning, accurate dead reckoning, and extensive use of all available aids. The navigator must work very rapidly to obtain and interpret inflight observations. In general, low altitude flying affects the navigation problem because of reduced radar range, reduced visual capability, loss of reliable celestial techniques resulting from turbulence and/or frequent overcasts, and inconsistency of winds caused by terrain effects. In addition, the normal mechanics of navigation, such as writing, measuring, computing, and plotting, are made difficult to impossible by turbulence encountered at low altitudes.

PLANNING THE MISSION

The key to successful low level navigation is the careful and comprehensive planning accomplished prior to the flight. Every minute spent in flight planning helps to insure that the low level mission will be successful.

Route Determination

Carefully select the route to the target or destination with emphasis upon navigational check points and safety of flight. Turning points should be over or close to identifiable points such as those which provide good land-water contrast or give good radar definition at maximum range.

DIRECTNESS. To conserve time and fuel, the route must be as direct as possible. A direct route also minimizes the time spent within range of enemy defenses (surface-to-air missiles, all-weather interceptors, etc.).

PROCEDURE TURNS. Compute procedure turns for all turning points since the aircraft must roll out on course. Chapter 24 contains a series of tables which are used to compute procedure turns. If heading and groundspeed change in flight, use the tables to recompute a new procedure turn.

ALTITUDE. Terrain elevation, both along the intended flight path and adjacent to it, is an extremely important factor when planning mission altitude. Normal altitudes for low level combat missions are between 200 and 500 feet above ground level. On domestic training missions, planning must adhere to the flight rules contained in FLIP.

ALTIMETER ERRORS. Two types of altimeter error enter into consideration when planning a low level mission. They are caused by (1) differences in barometric pressure along the flight routes and (2) known deficiencies in the altimeter.

The navigator may obtain changes in barometric pressure along the route from the forecaster during the weather briefing or he can determine changes as he analyzes inflight weather before descending to the low altitude portion of the flight. Figure 26-1 illustrates a "D" Altimeter Setting Computation Graph which is used to compute the altimeter setting for low altitude. The procedure is based on readings taken at high altitude, before the final descent to low level.

The graph may be used to compute an altimeter setting for any true altitude. The data required for this computation are "D" values for any two altitudes. Obtain these "D" values from the weather forecaster prior to departure, from the appropriate weather chart, from inflight measured "D" values (by use of the radio altimeter or radar measurements and pressure altimeter), or by any combination of these methods. "D" equals true altitude minus pressure altitude. Altitude as observed on the radio altimeter (or measured by the radar set) plus terrain elevation is true altitude. Pressure altitude is read from the altimeter when it is set at 29.92.

Use of the graph involves three basic steps. These are:

1. Plotting "D" values at two or more altitudes, joining these values with straight lines, and extending these lines to other altitude levels as desired.
2. Finding the "D" value for some required intermediate altitude by graphical interpolation or for some altitude beyond the plotted values by graphical extrapolation.
3. Converting this "D" value to an altimeter setting.

Example:

Given: Radar measured "D" at 30,000 feet MSL = + 700 feet
Forecast "D" at 850 millibars = + 270 feet

Find: The altimeter setting for 10,000 feet MSL

Procedure:

1. Mark the intersection of 30,000 feet MSL and "D" of + 700 feet.
2. Mark the intersection of 850 mb and "D" of + 270 feet.
3. Draw a straight line between these two points.
4. Find the intersection of this line with 10,000 feet true altitude.
5. Read a "D" value of + 350 feet.
6. Read straight down the column to the bottom scale and find that for a "D" equal to + 350 feet, the altimeter setting is 30.30.

If the altimeter is set for 30.30, the altimeter

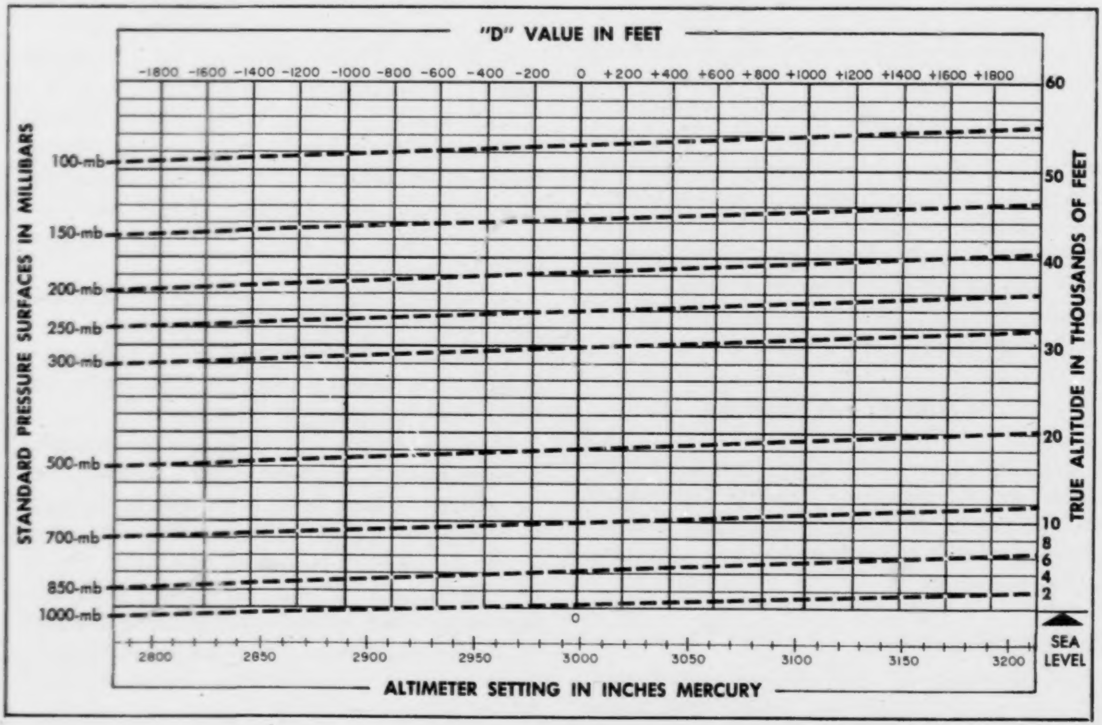


Figure 26-1. "D"/Altimeter Setting Computation Graph

should read 10,000 feet when the airplane is at a true altitude of 10,000 feet (plus or minus the altimeter error).

CAUTION

An altimeter setting computed by this method is accurate only for a given location at the altitude for which it was computed. For level-off at low level flight altitude, an altimeter setting is required for the level-off point.

In the example given, the level-off altimeter setting could be extrapolated from the graph by extending the line as required.

AIRSPEED. Normally low level missions are flight planned for true airspeeds which make mental DR computations simple. These are 240 knots (4 NM per minute), 300 knots (5 NM per minute), 360 knots (6 NM per minute), etc.

While it is important to maintain a constant TAS for accurate dead reckoning, the navigator may have to vary the TAS to control the time of arrival at turning points and over the target.

FUEL PLANNING. The problem of fuel consumption is a major consideration in low level planning. At low altitude, jet aircraft consume approximately twice the amount of fuel they use at high altitudes. In addition, combat sorties leave very small fuel tolerances for recovery. For this reason, the navigator must carefully plan all phases of the mission to conserve fuel. He usually assists the pilot in monitoring fuel quantities.

The problem is further complicated by load requirements for each mission. Therefore, compute the required amount of fuel carefully and hold excess fuel to a minimum.

WEATHER PLANNING. On combat missions, there is no designated minimum ceiling and visibility condition for low level flight. The wind velocities encountered at low altitude over land are generally light. Because of surface friction, particularly in rugged terrain, these winds can be relied on for short distances only. Because of this inconsistency and for reasons of simplicity, flight planning for high speed, low level missions over land is normally based on *no wind* condition.

In planning low level missions over water, however, inclusion of the wind in the flight plan is a matter of utmost importance. Overwater navigation depends entirely on dead reckoning because of the absence of check points with which to establish fixes and to make course corrections.

Chart Selection

Several charts are appropriate for low altitude navigation. One chart, which is specially designed for low level use, is the Operational Navigation Chart (ONC). The 1:1,000,000 scale permits identification of all visual and radar significant features, and the chart has excellent cultural and relief portrayal. For increased detail or slower-speed aircraft, Tactical Pilotage Chart (1:500,000) or a Joint Operations Graphic, Series 1501 AIR. (1:250,000) may be used.

It is possible to "mix" navigation charts. The enroute portion of the low level mission can be plotted on an ONC, while the Pilotage or Series 1501 AIR Chart may be used for the target area or for specific identification of check points. Aerial reconnaissance photos are helpful, though not always available. Annotate items of importance to navigation (turning points, descent points, high terrain, emergency airfields, etc.) on the chart. Label preplanned fixes with planned range and bearing information. In all cases, the annotations should be neat and compact for quick reference. Since time is critical at high speeds and low altitudes, the navigator must spend as little time as possible interpreting the information on his chart.

Planned Pacing

The navigator must choose suitable topographic or cultural returns for inflight fixing and must determine a pacing schedule to accommodate these fixes. He must plan the entire mission before takeoff. Consequently, what he accomplishes in the air is merely a follow-through of what he has previously flight-planned.

Since navigation demands flexibility, planning a pacing schedule involves two separate steps. First, a complete pre-mission plan is based on expected inflight conditions. Then, an alternate plan is constructed, in case the unexpected happens. For example, a 120 nautical mile navigation leg, flown at 360 knots, might accommodate three radar fixes. This plan becomes the primary pacing schedule for the leg. A secondary pacing plan might consider an unforeseen increase in groundspeed, and it would incorporate only two fixes.

Another instance of flexibility in planning might involve an excellent radar return, situated 20 miles from the planned course line. This return might provide a fix if the aircraft maintained its planned altitude. But if the inflight altitude is lower than anticipated, the return could be hidden by high terrain, or it may not appear at all. Consequently, an alternate radar return should be planned.

Route Study

To insure success in low level missions, the navigator must complete a thorough study of the route. To plan for enroute fixing, he should have an idea of how every point along the route will appear, either on the radarscope or visually. He can often take advantage of directional characteristics of natural or cultural features during this route study to simplify the navigation problem in the air.

RADAR PREDICTION. Radarscope interpretation can be preplanned for low level flights. The navigator should note significant returns such as land-water contrast, outstanding terrain features, and towns. The time of year is also important since radar returns during the winter may not appear the same as they do in other seasons of the year.

At low altitudes, the appearance of radar returns changes rapidly as the aircraft approaches or passes over or abeam them. Often the best identifying features of a check point cannot be distinguished by radar at low altitude. Because of this reduced radar range, the navigator should use dead reckoning procedures to verify and identify radar returns. Experience has shown that "no-return" areas, such as lakes and rivers, are more reliable for radar prediction and navigation, and furnish more accurate fixes than do towns or similar type returns. Tilt and gain settings are critical at low altitudes and must be closely monitored. The navigator can use radar navigation at low level very effectively in conjunction with the radar-computer unit. He can take reliable radar synchronous winds at low altitudes even below the design (altitude) limitations of the equipment if he follows specific synchronization procedures.

VISUAL PREDICTION. In addition to the problems experienced in radar prediction, other problems are encountered when forecasting map reading fixes. Weather effects such as precipitation, smoke, haze, or blowing dust may obscure features intending for fixing. Visual navigation is especially difficult when looking into the sun, particularly in haze conditions.

CELESTIAL. The instability of the aircraft during low level operations practically precludes the use of celestial observations. Celestial navigation is therefore used only as a last resort. If possible, deviation checks may be made shortly after takeoff; however, this is the exception rather than the rule if the entire flight is to be conducted at low level.

INFLIGHT PROCEDURES

Descent from Flight Altitude

Procedures for descent to low level altitudes are outlined in tactical manuals and aircraft flight manuals. During the descent, closely spaced fixing and DR techniques insure that the aircraft reaches the planned low altitude upon arrival at the start low level point.

Compute level-off altimeter settings using the "D" Altimeter Setting Computation Graph shown in figure 26-1. Cross-check these settings by adding the terrain elevation to absolute altitude (measured by radar or radio altimeter) to obtain the true altitude. Set the true altitude in the altimeter and read the altimeter setting on the barometric scale.

Maintaining Track

To insure meeting controlled times of arrival and to avoid terrain hazards, the low level flight must be flown exactly as planned. Every low level navigation leg is planned within a flight corridor for safety of flight reasons. There are several ways to maintain course, each of which has advantages and limitations. Some of the methods are described here.

FIVE-DEGREE RADIATING LINES. These are lines drawn from departure and destination (or turning point) radiating 5° either side of track. A visual inspection of a fix reveals the alter heading needed to fly directly to the next turning point. This heading alteration consists of two separate corrections, which are (1) the number of degrees required to parallel track and (2) the number of degrees required to converge into the turning point. The fix plotted in figure 26-2 shows that the aircraft has drifted approximately 2° off course to the right when measured from departure: therefore, the correction to parallel course is 2° left. The radiating lines from turning point indicate that it will take 3 more degrees to converge

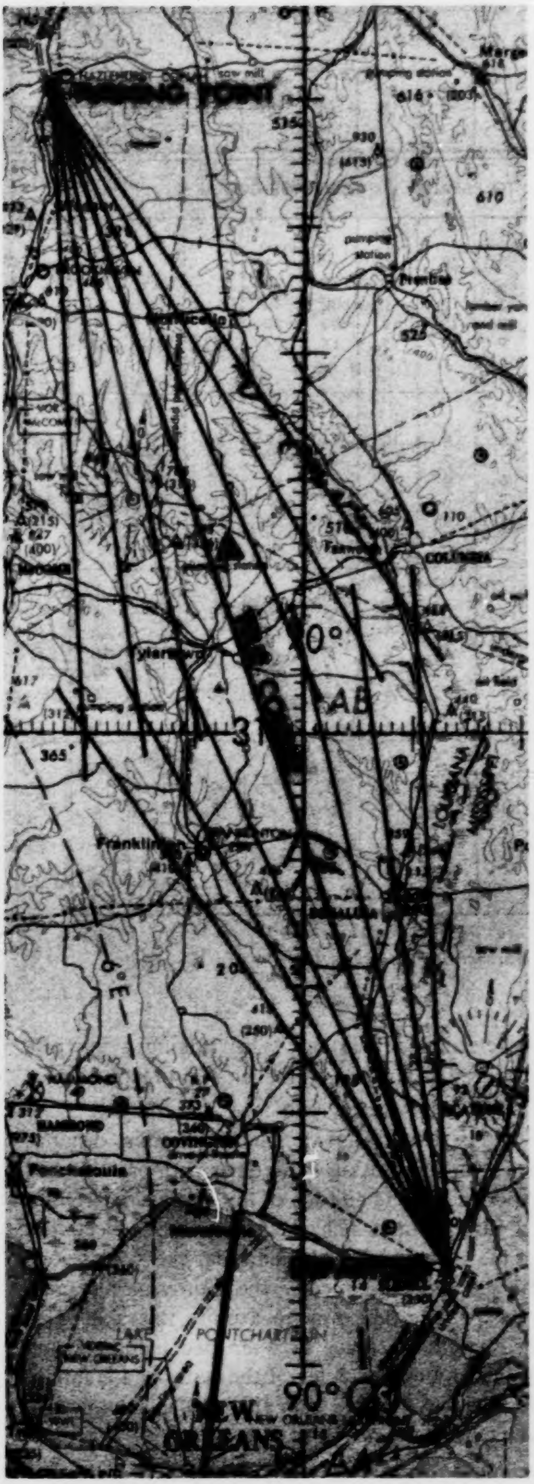


Figure 26-2. Five-Degree Radiating Lines

into the turning point. The total correction is 5° left.

This method is helpful where a leg of the route has few check points and annotations. Because the radiating lines tend to clutter the chart, they cannot be used where many check points are available, where the legs are too short, or where legs cross one another.

Off-Course Correction Tables. Off-course corrections can also be determined using the table shown in figure 26-3. Enter from the top of the table with the miles off-course, go vertically to the line representing miles flown, and read the correction to parallel. Do the same for the correction to converge, except that the "Miles Flown" represents miles to fly. *Add* the two corrections for the *total* course alteration to converge.

Correction to Intercept Course. The graph shown in figure 26-4 is used when it is necessary to intercept course rather then converge at the turning point. To use this graph, the entering arguments are nautical miles off course and groundspeed. The table can be used for fixed alterations of 15°, 30°, 45°, or 60°. Enter the graph on the left with nautical miles off course; go horizontally across the chart to the line representing groundspeed. Then go vertically to the top or bottom (depending on the desired degrees to alter) to read the time required to intercept course. After the alteration is made and the indicated time has elapsed, make an alteration to the original (or corrected) heading to maintain desired course.

Time Control

To provide positive control of several aircraft flying related low level missions, each sortie is assigned a particular time to arrive at each designated turning point and over the target zone. Therefore, every ETA *must* be met within close tolerances.

Annotate route legs on the chart with a series of small "speed lines" drawn across the leg. Space these speed lines, or "time ticks", one minute apart according to forecast groundspeed; e. g., six nautical miles apart for a planned groundspeed of 360 knots. These speed lines begin at the low level entry (starting) point and continue through the entire route to the target. With these speed lines, the navigator can check his time over each speed line and keep a running account of whether the aircraft is ahead of, or behind, the

MILES FLOWN OR TO FLY	MILES OFF-COURSE															
	1	2	3	4	5	6	7	8	9	10	15	20	25	30	40	50
	CORRECTION (IN DEGREES) TO PARALLEL OR CONVERGE COURSE															
10	6	12	17	24	30	37	44	53	64	90						
20	3	6	9	12	14	17	20	24	27	30	49	90				
30	2	4	6	8	10	12	14	15	17	19	30	42	56	90		
40	1	3	4	6	7	9	10	12	13	14	22	30	39	49	90	
50	1	2	3	5	6	7	8	9	10	12	17	24	30	37	53	90
60	1	2	3	4	5	6	7	8	9	10	14	19	25	30	42	56
70	1	2	3	3	4	5	6	7	7	8	12	17	21	25	35	46
80	1	1	2	3	4	4	5	6	6	7	11	14	18	22	30	39
90	1	1	2	3	3	4	4	5	6	6	10	13	16	19	26	34
100	1	1	2	2	3	3	4	5	5	6	9	12	14	17	24	30
110	1	1	2	2	3	3	4	4	5	5	8	10	13	16	21	27
120	0	1	1	2	2	3	3	4	4	5	7	10	12	14	20	25
130	0	1	1	2	2	3	3	4	4	4	7	9	11	13	18	23
140	0	1	1	2	2	2	3	3	4	4	6	8	10	12	17	21
150	0	1	1	2	2	2	3	3	3	4	6	8	10	12	15	19
160	0	1	1	1	2	2	3	3	3	4	5	7	9	11	14	18
170	0	1	1	1	2	2	2	3	3	3	5	7	8	10	14	17
180	0	1	1	1	2	2	2	3	3	3	5	6	8	10	13	16
190	0	1	1	1	2	2	2	2	3	3	5	6	8	9	12	15
200	0	1	1	1	1	2	2	2	3	3	4	6	7	9	12	14

Figure 26-3. Off-Course Correction Tables

required time schedule. If the need for an increase in groundspeed is apparent, he may increase airspeed or plan to turn short at the next turning point. If the aircraft arrives early at one of the speed lines, he may decrease airspeed or perform time losing maneuvers as explained in Chapter 25.

Fixing

Low altitude radar or visual navigation is a combination of dead reckoning and precision fixing. The DR position is essential, since it is difficult to differentiate among returns at low level. Without an accurate DR position, it is possible to misinterpret the pattern of returns surrounding the aircraft. To increase the chances of selecting correct returns and plotting accurate fixes, draw a line from the return through the course line, at a predetermined bearing. When taking a fix, plot distances from the returns on the preconstructed bearing lines.

ESTIMATING DISTANCES. Estimating distance from the air is a skill that comes with practice and experience. The altitude of the aircraft determines the distance at which check points or objects are visible. The higher the altitude, the farther one can see and consequently, the shorter all distances appear. The best way to acquire this skill is to measure the distance between two landmarks on the chart along each leg of the route and compare this known distance with the way it actually appears from the aircraft.

CREW COORDINATION. Specific coordination must be effected between the navigator and other aircrew members. The relatively short period of

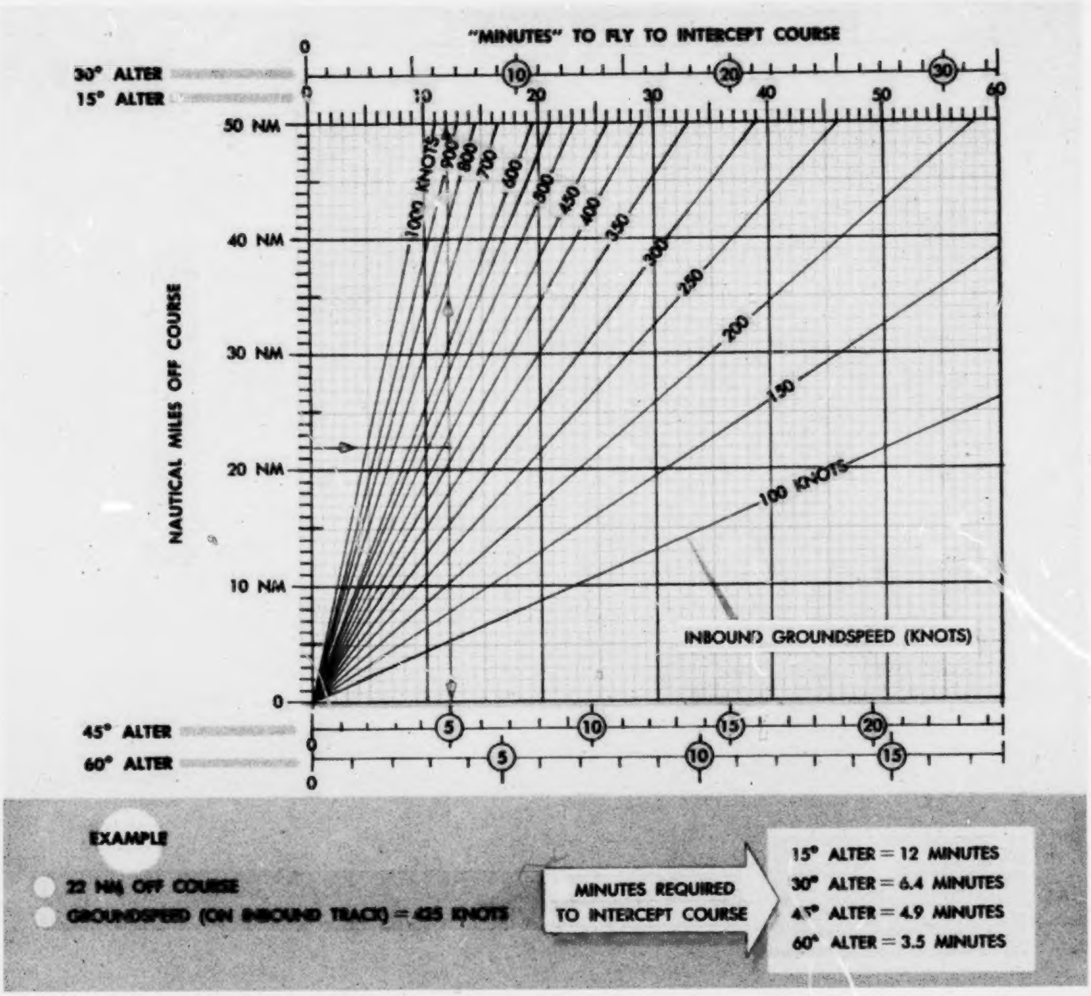


Figure 26-4. Correction to Intercept Course

time available to observe and identify check points makes any possible assistance from other crew members of vital importance to the navigator. The success of the mission ultimately depends upon crew coordination.

SUMMARY

The most important phase of the low level mission is the flight plan. If the mission is planned well and there is good crew coordination, mission success is greatly enhanced. The navigator should know what aids will be available, he should be familiar with all phases of the particular mission and study them until he has a clear mental picture of the flight, and finally, he should maintain good inflight DR procedures. If he does all this, the low level mission will be greatly simplified. If not, the chances of success are proportionately reduced.

CHAPTER 27

Automatic Navigation Systems

Navigation systems have been steadily improved over the years. The most significant improvement of systems occurred after World War II. Minute electronic parts and circuitry have enabled the installation of extremely complex pieces of equipment into aircraft. Prior to the development of these miniaturizations, such installations were either impractical or impossible.

One of the first pieces of equipment to be used as an airborne computer was the Air Position Indicator (API). It was introduced during the first years of World War II, and although it was primitive by today's standards, it was, at least, a beginning.

CLASSIFICATION OF NAVIGATION SYSTEMS

Types of Systems

Navigation systems now in use can be classified as either self-contained or ground-referenced.

SELF-CONTAINED. A self-contained system is complete in itself and does not depend upon the transmission of data from a ground installation. However, some self-contained systems, such as search radar and Doppler radar, do require transmission of energy *from the aircraft*. Other self-contained systems, such as the inertial system and celestial referenced aids, are completely passive in operation; that is, they do not transmit energy from the aircraft.

Aircraft equipped with self-contained systems can operate anywhere in the world without the assistance of ground-based aids. They have great flexibility since the accuracy of the system is not affected by the location of base lines, blind spots caused by terrain, or bad weather.

GROUND-REFERENCED. Ground-referenced aids include all aids which depend upon transmission of energy from the ground. For military purposes, the use of ground-referenced aids involves considerable risk, since in time of war the system provides a navigation aid for enemy as well as friendly forces. Other disadvantages of ground-referenced aids are the large installation and operating costs.

The Ideal System

Every navigation system has certain advantages and disadvantages. A particular navigation system is used in a situation where its advantages can be exploited while its disadvantages do not harmfully affect its use. In some cases, several aids must be provided to fulfill the requirements of different missions adequately. The ultimate objective of navigational research is to produce one system that can be used in any location to supply a complete navigational aid for all aircraft. If such an ideal system is developed, it should have the following characteristics:

GROUND INFORMATION. The system must indicate the ground position of the aircraft.

GLOBAL COVERAGE. The ideal system must be capable of positioning and steering the aircraft accurately and reliably any place in the world.

SELF-CONTAINED. The ideal system must not rely upon ground transmissions of any kind.

PASSIVE OPERATION. The system must not betray the position of the parent aircraft by transmitting signals of any kind.

IMMUNE TO COUNTERMEASURES. The system must not be susceptible to countermeasures of any type.

Useless to Enemy. The system must not provide navigational aid or intelligence of any kind to enemy forces.

Flexible. Unlike some navigational systems which place the aircraft or missile on the final heading very shortly after takeoff, the ideal system must be flexible. The system must track the aircraft even though unplanned deviations are made from the preflight course. The system must also be capable of operating at any altitude and at any speed within the capability of the aircraft.

DOPPLER

Since man first flew, he has searched for a way to determine aircraft groundspeed and drift angle without aid from the ground. Various models of the driftmeter provided only a partial answer to the problem. Its use consumed a great deal of the navigator's time, and it could not be used over smooth water or when weather obscured the surface. Other devices were proposed, but these met with equally limited success. The first breakthrough came with Doppler radar.

Doppler radar provides the navigator with continuous, instantaneous, accurate readings of groundspeed and drift angle in all weather conditions, both over land and over water. It does this automatically with equipment that is of practical size and weight. Its operation makes use of the Doppler effect.

Doppler Effect

The Doppler effect was discovered in 1842 by Christian Johan Doppler. This effect simply stated is that transmitted energy undergoes an apparent shift in frequency as the distance between the transmitter and receiver decreases or increases. It is this frequency shift which makes possible the instantaneous sensing and measuring of groundspeed and drift angle by Doppler radar.

The Doppler effect applies to all wave motion including electromagnetic, light, and sound. The effect on sound waves can be observed by listening to the whistle of a passing train. As the train approaches, its whistle as heard by a stationary observer has a fairly steady pitch; that is, higher than the true pitch. As the train passes, the pitch drops quickly to a frequency below the true pitch and remains at approximately the lower value as the train moves away from the observer. This principle is illustrated in figure 27-1.

The *change in pitch,* which is a *change in frequency,* is due to the relative motion between the train and the observer. Moreover, the degree of change is proportional to the relative velocity between the two. It should be noted that this is actually a change in frequency to the observer standing near the track but to an observer riding on the train there is no change in pitch and he hears a steady whistle. The reason for this shift is that as the train speeds ahead from left to right, as in the illustration, each successive sound wave is emitted slightly farther ahead on its path. The waves, though still spreading in all directions at a constant speed, no longer share a common center. They crowd together in front causing a higher frequency. Behind the train the distance between the waves is stretched, the frequency is decreased, and the pitch is therefore lowered.

Single Doppler Shift. It must be understood in the explanation given above, that the forward motion of the train does not increase the speed of sound. Under constant atmospheric conditions, the speed of sound is always constant. Instead, the forward motion of the train slightly compresses the wave length of sound, as illustrated in figure 27-2, producing a higher frequency which the observer at *A* hears as a higher pitch. When the train whistle is directly abeam the observer at *A′*, a true pitch is heard because relative motion between "transmitter" and "receiver" is zero. As the train moves off, its forward motion slightly expands the wave length of sound, and the observer at *A″* hears a lower-than-true pitch. This illustration is an example of single Doppler shift.

Note that this explanation describes the whistle's pitch as "fairly constant" as the train approaches and moves off. It actually drops slightly. This is because the observer stands at some distance from the railroad tracks. To hear an exactly constant pitch as the train approaches and moves off, the observer must stand in the middle of the tracks. When the observer stands off to one side or the other, a second variable comes into play which causes the whistle pitch to drop gradually as the train approaches, rapidly as the train passes, and again gradually as the train moves off. This variable is the angle gamma (γ) shown in figure 27-1. The angle is measured between the train's line of

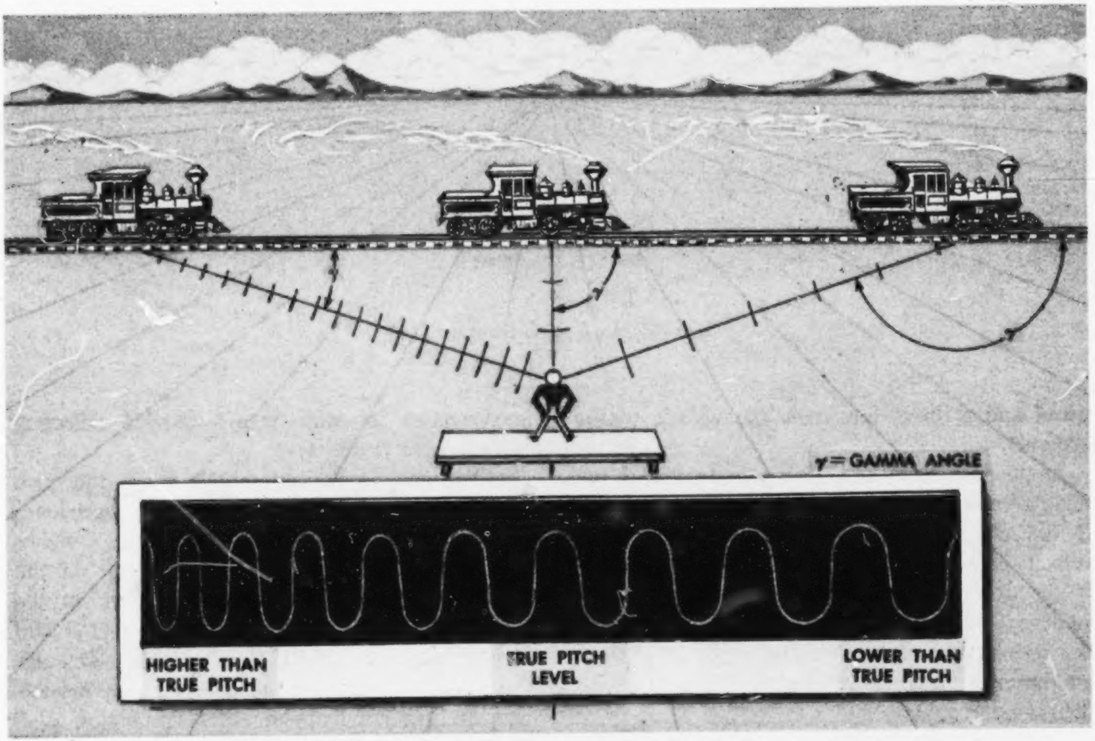

γ = GAMMA ANGLE
HIGHER THAN TRUE PITCH
TRUE PITCH LEVEL
LOWER THAN TRUE PITCH

Figure 27-1. Doppler Effect

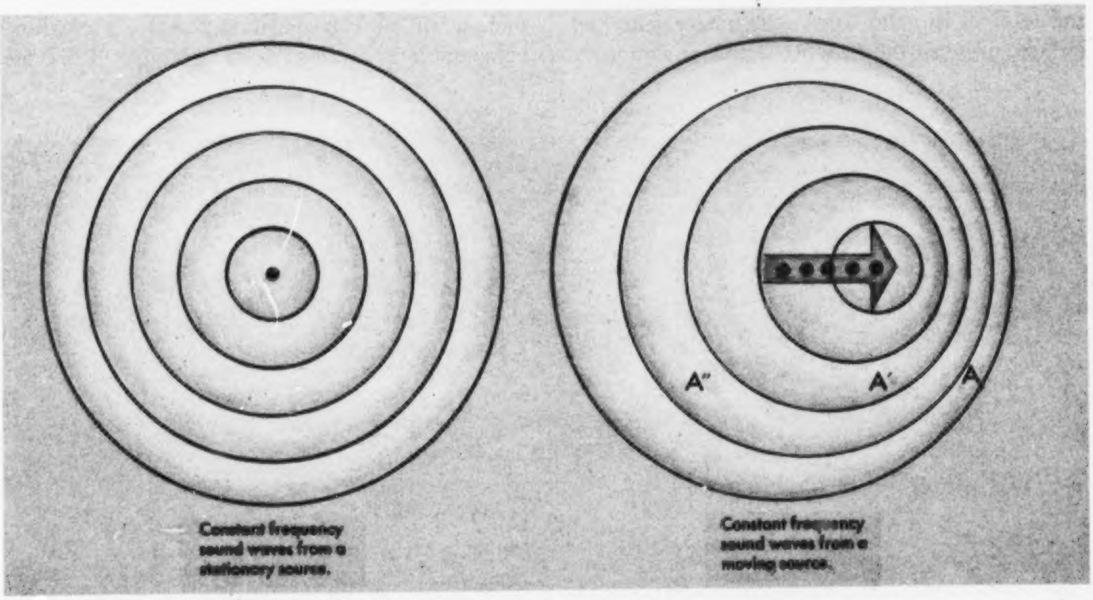

A″
A′
A
Constant frequency sound waves from a stationary source.
Constant frequency sound waves from a moving source.

Figure 27-2. Moving Source of Sound Affects Frequency Reception

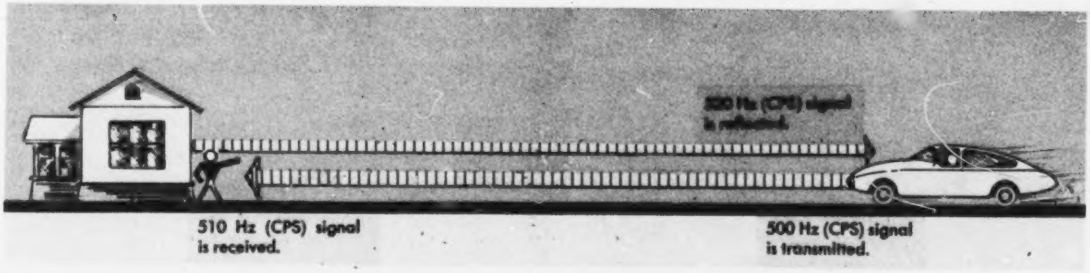

520 Hz (CPS) signal
is reflected.
510 Hz (CPS) signal
is received.
500 Hz (CPS) signal
is transmitted.

Figure 27-3. Double Doppler Shift

travel and a direct line from the whistle to the observer.

In any case, Doppler shift is proportional to the relative velocity between the train and the observer. If the observer stands on the tracks, relative velocity is determined by the train's rate of closure. If the observer stands off to the side, relative velocity is determined by the combined effect of the train's rate of closure and angle γ. Stated another way, relative velocity is proportional to the cosine of angle γ.

Angle γ changes gradually when the train is at a distance, and rapidly as the train passes. Thus the whistle's pitch drops gradually when the train is at a distance, and rapidly as the train passes.

DOUBLE DOPPLER SHIFT. Double Doppler shift occurs when the emitting source is in motion and receives its echo from a stationary reflecting surface, or when the emitting source is stationary and receives its echo from a moving reflecting surface. See figure 27-3.

If the man in the automobile blows the horn (producing a tone of 500 Hz). as he approaches the building, a man by the building hears a higher tone (510 Hz, a single Doppler shift). If the building reflects the horn's sound back to the automobile, the driver hears the echo at a still higher frequency (520 Hz, a double Doppler shift). This occurs in much the same manner with an airborne Doppler radar set. Figure 27-4 illustrates a functioning Doppler system transmitting a silent beam of radar energy from the aircraft to the ground. The beam is transmitted at a known angle γ from the direction of aircraft travel. The ground reflects some radar energy back to the aircraft. The Doppler system is in motion while the ground is stationary, a situation comparable to the automobile example. Thus the

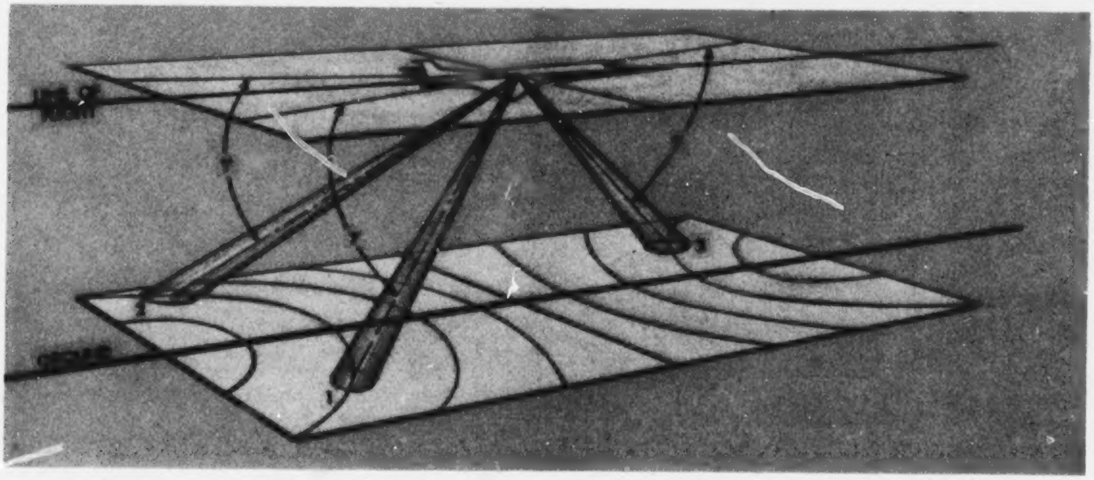


Figure 27-4. Gamma Angle from Airborne Doppler System

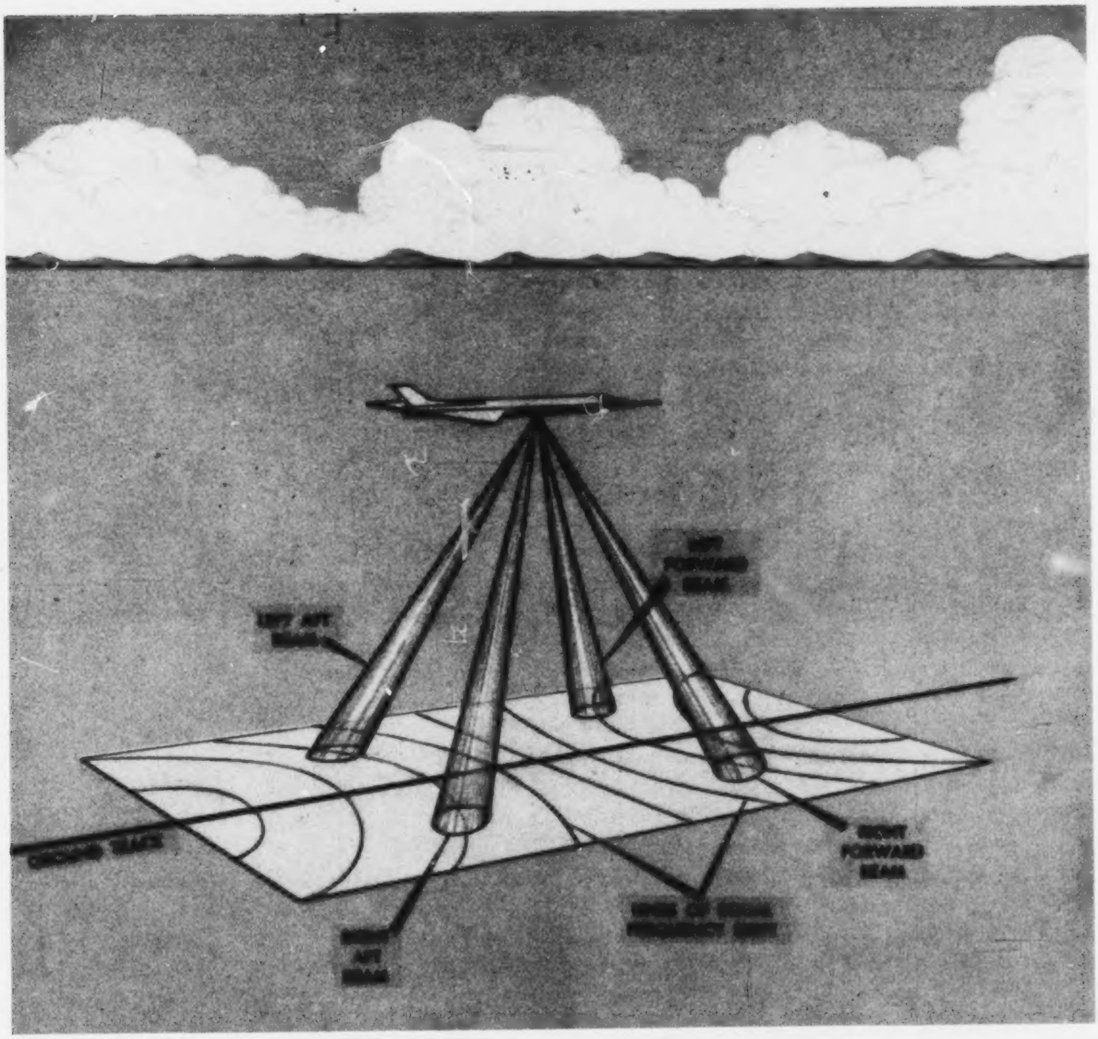


Figure 27-5. Configuration for Groundspeed Measurement

frequency of radar energy returned to the aircraft is increased by double Doppler shift. Since angle γ is intentionally kept constant, any variation in the frequency of returned radar energy represents a proportional variation in groundspeed.

Antenna Configuration

Two basic Doppler radar systems are currently in use, the four-beam and the three-beam. Both types use either continuous wave (CW) or pulse wave (PW) transmission. CW transmission requires one antenna for transmission and a second antenna for reception.

FOUR-BEAM DOPPLER RADAR. Figure 27-5 illustrates the four-beam system. Two beams are directed forward and two beams are directed aft. The system computes groundspeed and drift. Groundspeed is measured by comparing frequencies from the forward beams with frequencies from the aft beams. The amount of frequency shift is converted to groundspeed.

Frequencies from the four beams are compared in a sightly different manner to measure drift. The frequency shift between the right forward and left aft beams is compared with the frequency shift between the left forward and right aft beams. If

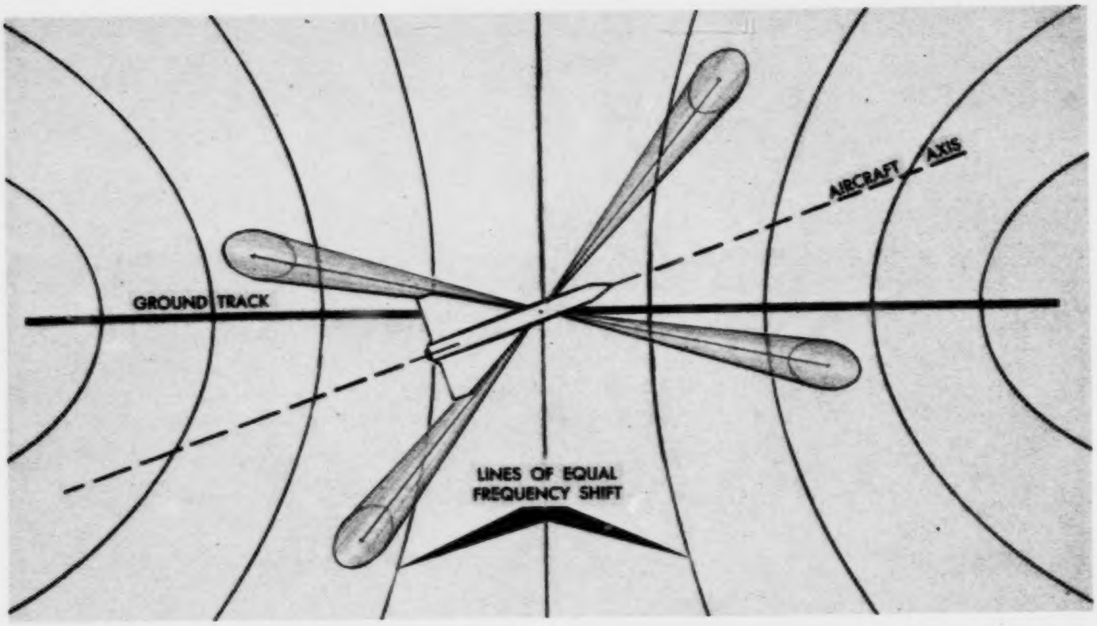

AIRCRAFT AXIS
GROUND TRACK
LINES OF EQUAL FREQUENCY SHIFT

Figure 27-6. Antenna Position Before Drift is Measured

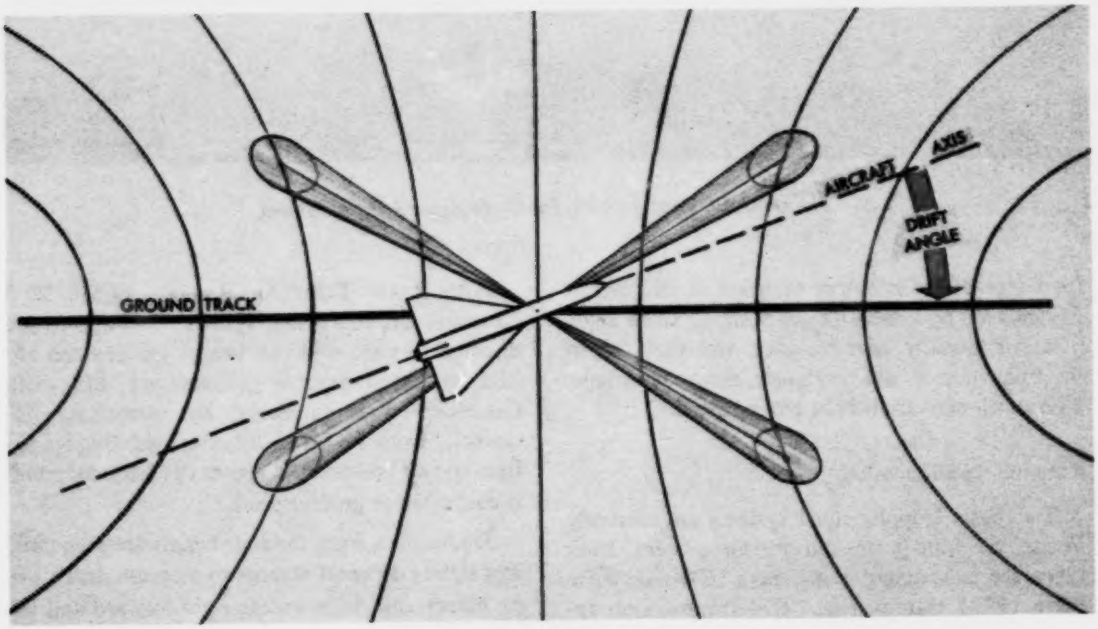

AIRCRAFT AXIS
DRIFT ANGLE
GROUND TRACK

Figure 27-7. Antenna Position After Drift is Measured

the two shifts are equal, drift is zero. Figure 27-6 illustrates the right forward and left aft beams producing the higher frequency shift; thus, drift is to the right. If the left forward and right aft beams produce the higher frequency shift, drift is to the left. Figure 27-7 illustrates that the system's drift computing elements have sensed the difference in frequency shift and used this difference to align the antenna with ground track. When the antenna has been so aligned, the two sets of beams indicate equal Doppler shifts, or zero drift, while the angle to which the antenna has been rotated equals drift.

THREE-BEAM DOPPLER RADAR. The three-beam Doppler principle of operation differs somewhat from that of the four-beam Doppler. The three beams are directed 70° below the horizontal plane, and are offset 20° from the longitudinal axis of the aircraft. This arrangement of the beams, illustrated in figure 27-8, is called the lambda configuration because it resembles the Greek letter lambda (λ).

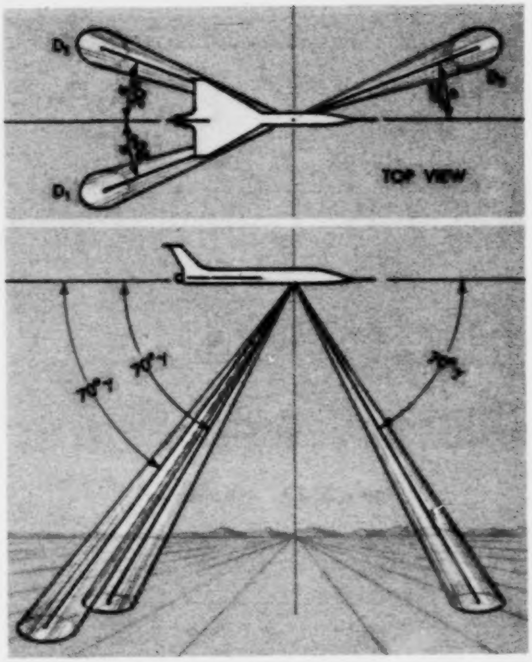


Figure 27-8. Three-Beam Doppler Radar

The frequency from each beam undergoes a shift because of forward motion, wind drift, and vertical travel of the aircraft. The frequency shift is a function of aircraft velocity. The aircraft forward, lateral, and vertical velocities are obtained by combining these frequency-shifted signals. Vertical velocity is determined by the frequency shifts from beams D_3 minus D_1. Forward velocity is determined by the frequency shifts from D_3 plus D_2. Lateral velocity is determined by the frequency shifts from D_2 minus D_1.

The three velocities are resolved into velocities *along* heading and *across* heading. The resultant equals groundspeed and the angle equals drift. See figure 27-9. Drift is then resolved around true heading to produce ground track.

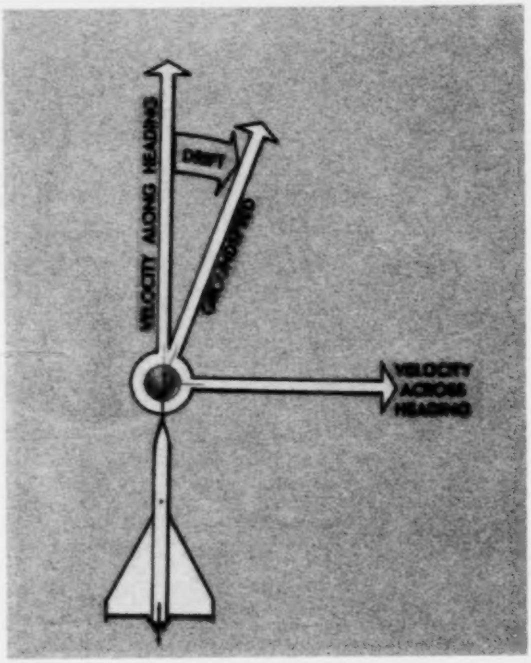


Figure 27-9. Resultant Groundspeed and Drift Angle

Summary

Since the primary outputs of Doppler are drift angle and groundspeed, it is obvious that any navigation problem requiring these components has received a boon with the innovation of Doppler. Because Doppler information provides an accurate DR position, the accuracy of celestial navigation is increased since it basically depends on the DR position. Doppler also possesses the accuracy necessary to complete rendezvous and to contribute to the solution of bombing problems.

AUTOMATIC ASTROTRACKER

The automatic astrotracker is an optical electromechanical system which provides a continuous true heading reference. Since it uses a celestial rather than magnetic reference, the astrotracker is independent of the earth's magnetic field. It can therefore provide accurate navigation data in both hemispheres and in both polar regions.

The astrotracker can locate, lock on, and track celestial bodies of the first, second, or third magnitude. These include stars with the photomagnitude of Polaris or brighter, planets, and the sun.

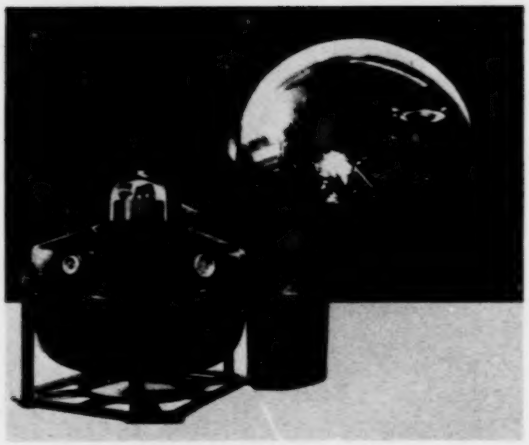


Figure 27-10. Astrotracker

Components

The automatic astrotracker system includes the following groups:

- Astrotracker
- Control Group
- Indicator Group
- Amplifier and Computer Group
- Power Group

ASTROTRACKER. The astrotracker, shown in figure 27-10, is composed of a tracking telescope which is stabilized by a vertical reference gyro. A hemispherical glass dome is mounted at the top center of the astrotracker housing. The dome projects above the fuselage skin and admits light from celestial bodies to the tracking telescope. The astrotracker modulates the light waves and a phototube converts the modulated signal to a usable electric signal for the computer group.

CONTROL AND INDICATOR GROUPS. The control group contains the control panels required for operating the astrotracker system and inserting the required input information. The indicator group displays the input and computed output information. See figure 27-11.

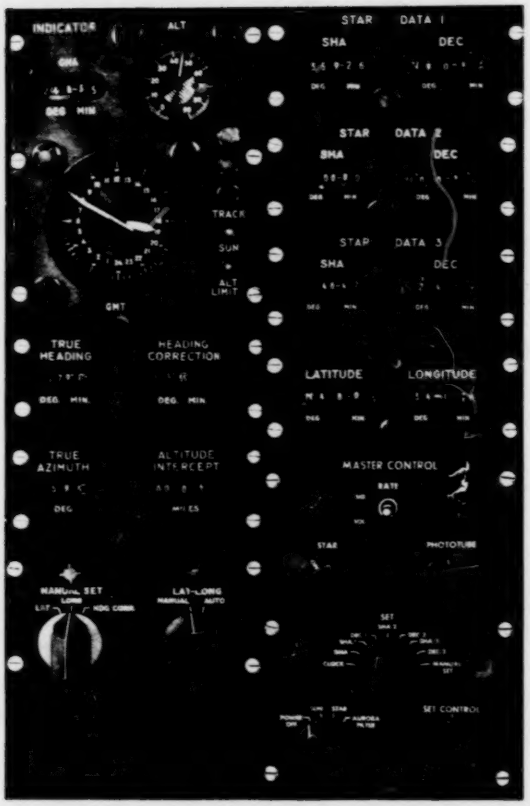

INDICATOR
ALT
GHA
DEG MIN
TRACK
SUN
ALT LIMIT
GMT
TRUE HEADING
DEG. MIN.
HEADING CORRECTION
DEG. MIN
TRUE AZIMUTH
DEG
ALTITUDE INTERCEPT
MILES
MANUAL SET
LONG
LAT
HDG CORR
LAT-LONG
MANUAL
AUTO
STAR DATA 1
SHA
DEC
DEG
MIN
STAR DATA 2
SHA
DEC
STAR DATA 3
SHA
DEC
LATITUDE
LONGITUDE
MASTER CONTROL
RATE
STAR
PHOTOTUBE
SET
SHA 2
DEC 1
DEC 2
SHA 1
SHA 3
SHA
DEC 3
CLOCK
MANUAL SET
SET CONTROL
STAR
POWER OFF
AURORA FILTER

Figure 27-11. Astrotracker Control and Indicator Groups

POWER GROUP, AND AMPLIFER AND COMPUTER GROUP. The power group supplies the required power to all astrotracker systems while the amplifier and computer group determines the output data of true heading, true azimuth, celestial altitude, altitude intercept, and heading correction.

Operation

To accomplish its function, the astrotracker system solves for the celestial values of altitude and azimuth. It must have these necessary inputs:

latitude, longitude, Greenwich Hour Angle, Sidereal Hour Angle, and declination.

INSERTING INFORMATION. Though normally supplied by automatic navigation computers, latitude and longitude can be manually inserted by the navigator. All celestial information can be obtained from the *Air Almanac* (GHA of the body, GHA of Aries, SHA, and declination). Stars available for tracking can be obtained from the morning, evening, and polar sky diagrams in the *Air Almanac*. The photo-magnitude of stars (labeled S-4) are also listed in the *Air Almanac*. The phototube is used to convert the light from celestial bodies to an electrical signal. Its ability to sense light from celestial bodies differs from the ability of the eye to see the light. For example, Antares has a visual magnitude of 1.2 but a photo-magnitude of 3.7.

COMPUTING AND DISPLAYING INFORMATION. After the required information is inserted, a mechanical analog computer computes the true azimuth (Zn) and the computed altitude (Hc). These values are displayed for the navigator's reference as well as being used in the system to position the optical telescope in altitude and azimuth. However, to position the optical telescope in azimuth, the relative bearing of the body to the aircraft must be computed. The astrotracker system accomplishes this by subtracting the best available true heading from the true azimuth (Zn − TH = RB). The best available true heading used for the computation of relative bearing is supplied from an alternate true heading system. The selected body should then be within the optical telescope search pattern.

When the telescope locks onto the body, the astrotracker system computes two values: altitude intercept and heading correction. Altitude intercept is the difference between the computed altitude (Hc) which initially positioned the telescope and the actual altitude of the body. Heading correction is the difference between the computed relative bearing and the actual relative bearing of the body. Next, the astrotracker computes the true heading by applying this correction value to the best available true heading supplied by the alternate true heading system.

With the advent of high speed aircraft, the need for accurate heading information becomes more and more acute. The astrotracker supplies this heading information with an accuracy of ± 6 minutes of arc.

Astrotrackers are also designed for space vehicles, missile guidance systems, and satellite applications. They can lock onto inertially stable star directions to serve as sensors of space vehicle attitudes. When used on nearby solar bodies, the direction information can be used with respect to solar coordinate systems to develop accurate position information as well as vehicle attitude.

INERTIAL NAVIGATION SYSTEM (INS)

Inertial navigation is now accepted as the ultimate in navigation systems for two reasons:

- An inertial system neither transmits nor receives any signal, so it is unaffected by enemy countermeasures.
- Theoretically there is no accuracy limitation in an inertial system. Technology and manufacturing precision can be considered as the factors affecting accuracy.

An inertial navigator can measure groundspeed in the presence of wind and is completely independent of operating environments. The need for a system with these properties has spurred development to the point where the inertial navigator is as good as, or better than, other automatic navigation systems. The inertial navigator provides accurate velocity information instantaneously for all maneuvers, as well as an accurate attitude and heading reference.

Principles

The basic principle of inertial navigation is the measurement of acceleration or displacement, rather than the measurement of airspeed and wind velocity as is necessary in the use of dead reckoning. This measuring of displacement is done with accelerometers. The four basic components in any inertial navigation system are:

1. A stable platform oriented to maintain the accelerometers horizontal to the earth and to provide azimuth orientation.
2. The accelerometers arranged on the platform to supply specific components of acceleration.
3. The integrators to receive the output from the accelerometers and to furnish velocity and distance.
4. A computer to receive the signals from the integrators and to change the distance traveled into position in the selected coordinates.

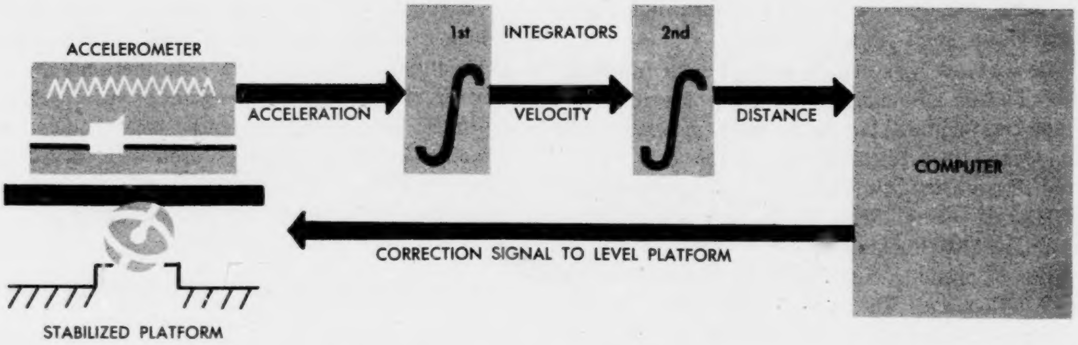

ACCELEROMETER
ACCELERATION
1st
INTEGRATORS
2nd
VELOCITY
DISTANCE
COMPUTER
CORRECTION SIGNAL TO LEVEL PLATFORM
STABILIZED PLATFORM

Figure 27-12. A Basic Inertial System

Figure 27-12 shows that the accelerometers are maintained horizontal to the earth by means of a gyro stabilized platform. A signal is transmitted from the accelerometer to the integrators, which perform a double integration. Distance is fed into the computer where two operations are performed; first, a position is determined in relation to the reference system used, and second, a signal is sent back to the platform to reposition the accelerometer.

Accelerometer

Acceleration measuring devices are the heart of all inertial systems. It is most important that all possible sources of error be eliminated and that the accelerometers have a wide range of measurements. Very slight accelerations or even decelerating quantities need to be recorded. Changes in temperature and pressure must not affect the output of acceleration. An accelerometer consists of a pendulous mass which is free to rotate about a pivot axis in the instrument. There is an electrical pickoff which converts the rotation of the pendulous mass about its pivot axis into an output signal. This output signal is used to torque the pendulum to hold it in position and, since the signal is proportional to the measured acceleration, it is sent to the navigation computer as an acceleration output signal (figure 27-13).

However, the accelerometers cannot distinguish between actual acceleration and the force of gravity. Acceleration, to be meaningful, must be computed relative to the earth. This means that the accelerometers must be kept level in relation to the earth's surface (perpendicular to the local vertical) if acceleration in the horizontal plane is to be measured. The gyroscopes keep the accelerometers level and oriented in a north-south and east-west direction.

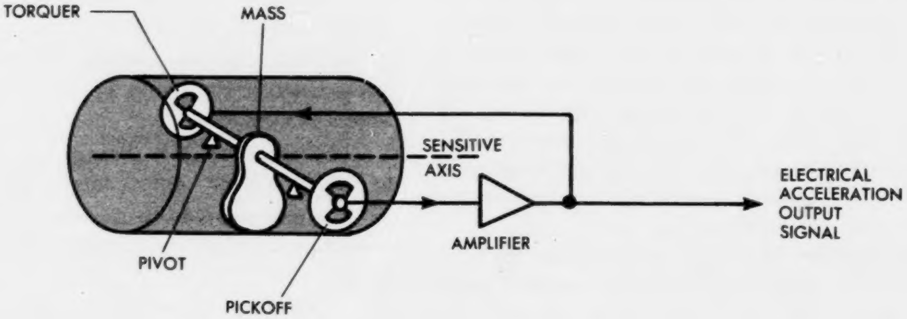

TORQUER
MASS
SENSITIVE AXIS
ELECTRICAL ACCELERATION OUTPUT SIGNAL
AMPLIFIER
PIVOT
PICKOFF

Figure 27-13. Accelerometer

In an aircraft, acceleration must be measured in all directions. To do this three accelerometers are mounted mutually perpendicular (orthogonal) in a fixed orientation. To convert acceleration into useful information the acceleration signals must be processed to produce velocity and then the velocity information must be processed to get the distance traveled. It is true that if acceleration is integrated with respect to time, velocity results. It is also true that if velocity is integrated, the result is distance. Any inertial system is based on the integration of acceleration to obtain velocity and distance. Acceleration is a vector quantity and has not only magnitude but also direction.

Integrator

The integration of both acceleration and velocity is very critical and the highest accuracy is essential. There are two types of integrators, the analog and the digital. One of the most used analog integrators is the RC amplifier, which uses a charging current stabilized to a specific value proportional to an input voltage. Another analog integrator is the AC tachometer-generator, which uses an input to turn a motor; the motor physically turns the tachometer-generator, producing an output voltage. The rotation of the motor is proportional to an integral of acceleration. Simply stated, the processing of acceleration is done with an integrator. All an integrator does is to produce an output which is the mathematical integral of the input, or in other words, the input signal multiplied by the time it was present (figure 27-14).

Stable Platform

Gyros are mounted on a platform with the accelerometers and control the orientation of the platform. All inertial systems use a gyro-stabilized platform to maintain accelerometer orientation. Each platform must contain a minimum of two gyros. If rate gyros are used, three gyros are needed. Each gyro must have its own independent operating loop. The effectiveness of the platform is determined by all parts of the platform, not just the gyros, to include torque motors, servo motors, pickoffs, amplifiers, and wiring. The gyro presents the major problems, particularly concerning precession. Many later developments have appeared, including the air bearing gyro, which has only 1/10,000,000 the friction of a standard gyro and its real precession is negligible. Other gyros have real precession rates of less than 360 degrees in 40 years. Platforms have been used for years in bombing and fire control systems; autopilots use a basic platform. Inertial navigation simply requires a stable platform with higher specifications of accuracy.

A gyro-stabilized platform on which accelerometers are mounted is called a *stable element*. It is isolated from the aircraft angular motions by gimbals. A simple diagram of a two-degree-of-freedom gyro mounted on a single-axis platform is shown in figure 27-15.

A gyro tends to remain in its original position when it is up to speed. Any displacement of the stable element from its frame of reference is sensed by the electrical pickoffs in the gyroscopes. These electrical signals are amplified and used to drive the platform gimbals to realign the stable element.

More advanced inertial navigation systems have a four-gimbal platform in a three-axis configuration. The order of gimbal axis is as follows, starting with the innermost axis: azimuth, inner roll, pitch, and outer roll (figure 27-16).

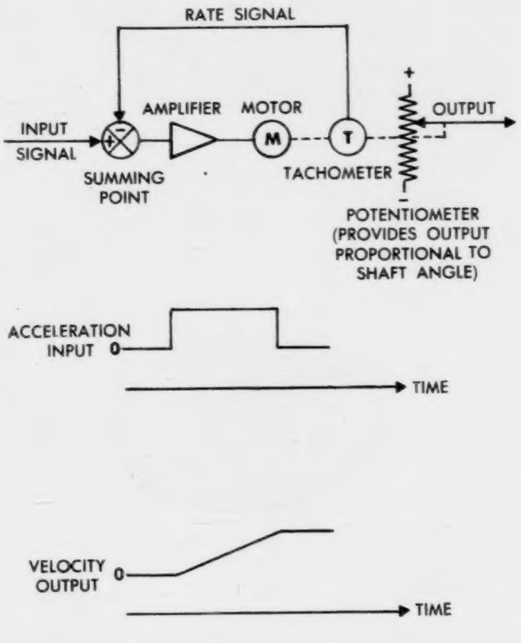


Figure 27-14. Integrator

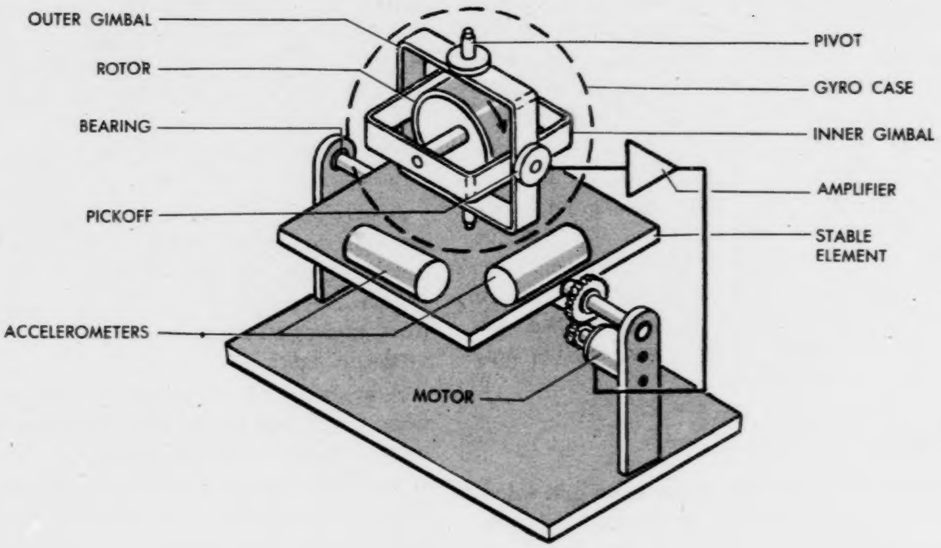

OUTER GIMBAL
ROTOR
BEARING
PICKOFF
ACCELEROMETERS
MOTOR
PIVOT
GYRO CASE
INNER GIMBAL
AMPLIFIER
STABLE ELEMENT

Figure 27-15. Stable Platform

The four-gimbal mounting provides a full 360-degree freedom of rotation about the stable element, thus allowing it to remain level with respect to local gravity and to remain oriented to true north. This is north as established by the gyros and accelerometers, regardless of the inflight attitude of the aircraft. The azimuth, pitch, and outer roll gimbals have 360-degree freedom of rotation about their own individual axis. The fourth or inner roll gimbal has stops limiting its rotation about its axis. This gimbal is provided to prevent gimbal lock, which is a condition that causes the stable element to tumble. Gimbal lock can occur during flight maneuvers, such as a loop, when two of the gimbal axis become aligned parallel to each other, causing the stable element to lose one of its degrees of freedom.

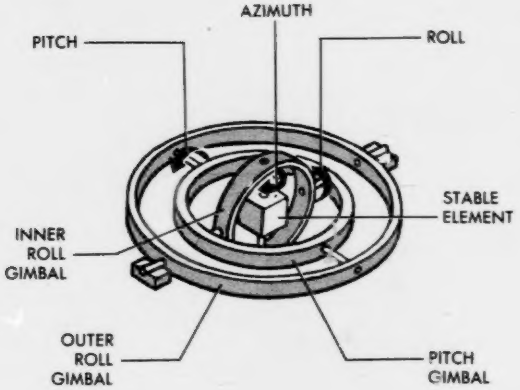

AZIMUTH
PITCH
ROLL
STABLE ELEMENT
INNER ROLL GIMBAL
OUTER ROLL GIMBAL
PITCH GIMBAL

Figure 27-16. Gimbal Platform

Measuring Horizontal Acceleration

The key to a successful inertial system is absolute accuracy in measuring horizontal accelerations. A slight tilt will introduce a component of earth's gravity and incorrect acceleration will be measured (figure 27-17).

Keeping the accelerometers level is the job of the feedback circuit. The computer calculates distance traveled and, via the feedback link, moves the accelerometer through an equivalent arc. The problem of aligning the accelerometer using this method is complicated by the following factors:

- The earth is not a sphere, but an oblate spheroid or geoid.

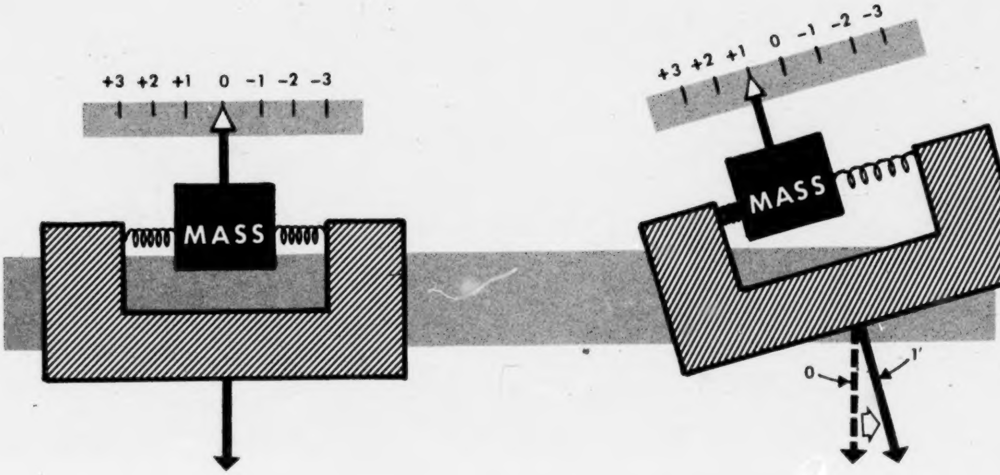

+3 +2 +1 0 -1 -2 -3
MASS
+3 +2 +1 0 -1 -2 -3
MASS
0
1'

Figure 27-17. Effect of Accelerometer Tilt

- The rotation of the earth produces a centrifugal force which deflects the specific force of gravity.
- Because the earth is not a smooth surface, there are local deviations in the direction of gravity.

The feedback circuit operates on the premise that the arc traversed is proportional to distance traveled. Actually, the arc varies considerably because of the earth's shape; the variation is greatest at the poles. The computer must solve for this irregularity in converting distance to arc.

The accelerometers are kept level relative to astronomical rather than geocentric latitude. Using the astronomical latitude, the accelerometers are kept aligned with the local horizon and also with the earth's gravitational field. The earth's rotation produces a centrifugal deflection that causes gravity to be perpendicular to astronomical latitude (figure 27-18).

Local abnormalities in the earth's gravitational field are of minor concern. They are compensated for only in vehicles with short inertial guidance terms, such as ballistic missiles.

Accelerometers are kept level by feedback from the computer. Feedback is needed because of two effects, both called *apparent precession*. If the inertial unit were stationary at one point on the

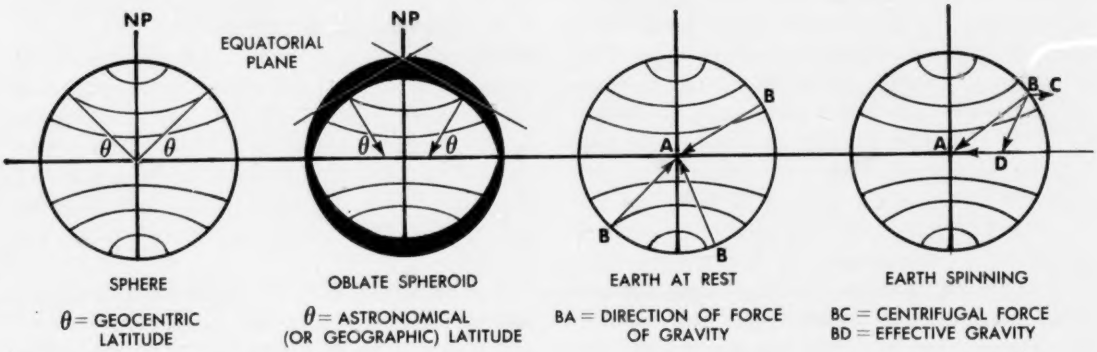

NP
EQUATORIAL PLANE
NP
θ
θ
θ
θ
B
A
B
B
B
C
A
D
SPHERE
θ = GEOCENTRIC LATITUDE
OBLATE SPHEROID
θ = ASTRONOMICAL (OR GEOGRAPHIC) LATITUDE
EARTH AT REST
BA = DIRECTION OF FORCE OF GRAVITY
EARTH SPINNING
BC = CENTRIFUGAL FORCE
BD = EFFECTIVE GRAVITY

Figure 27-18. Effect of Earth Rotation on Gravity Field

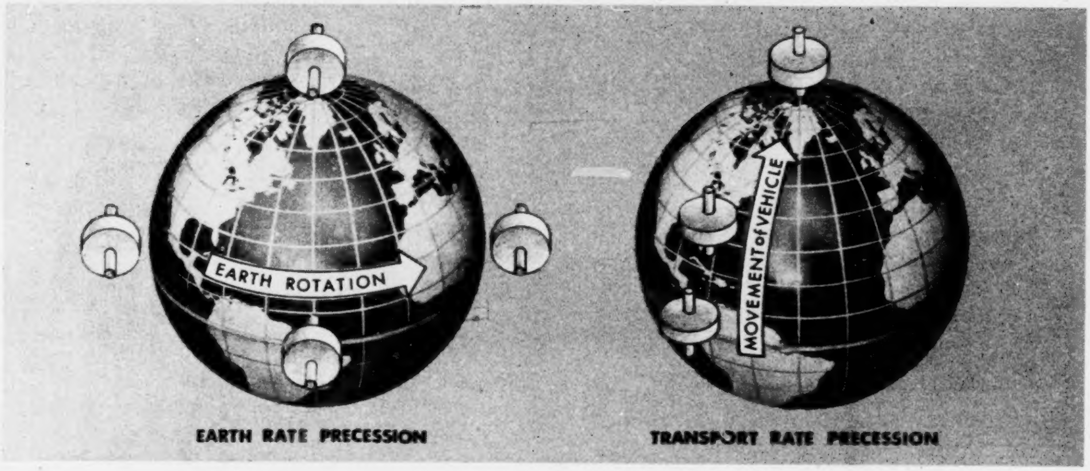


Figure 27-19. Apparent Precession

earth, it would be necessary to rotate the accelerometers to maintain them level, because of the earth's angular rotation of 15 degrees per hour. Also, movement of the stabilized platform would require corrections to keep the accelerometers level. When using a local horizontal system in which the accelerometers are maintained directly on the gyro platform, the gyro platform must be processed by a signal from the computer to keep the platform horizontal. Apparent precession is illustrated in figure 27-19.

A slight error in maintaining the horizontal would induce a major error in distance computation. If an accelerometer picked up an error signal of 1/100 of the G-force, the error on a one-hour flight would be 208,000 ft. Dr. Maxmillian Schuler, in 1923, showed that a pendulum with a period of approximately 84 minutes could solve the problem of eliminating inadvertent acceleration errors. The fundamental principle of the 84-minute theorem is that if a pendulum had a radius equal to that of the earth, gravity would have no effect on the bob because the center of the bob would be at the center of gravity of the earth. If a pendulum has a period of 84 minutes, it will indicate the vertical regardless of acceleration of the vehicle. The Schuler pendulum phenomenon prevents the accumulation of errors caused by the measurement of gravity, although it will not compensate for errors in azimuth resulting from precession of the steering gyro. The amplitude of the Schuler cycle depends upon the overall accuracy of the system. Figure 27-20 shows the Schuler-tuned system.

A gyro that is up to speed and is unslaved, or not torqued, is space oriented and will appear to move with respect to the surface of the earth. This is undesirable for aircraft inertial navigators, because the accelerometers will not be kept perpendicular to the local vertical. To earth-orient a gyro, the control of apparent precession is used. If a force is applied to the axis of a spinning gyro wheel which is free to move in a gimbaling structure, the wheel will move in a direction at right angles to the applied force. This is called "torquing" a gyro and can be considered as *mechanized or induced precession.* A continuous torque, applied to the appropriate axis by electromagnetic elements called torques, re-orients the gyro wheel to maintain the stable element level with respect to the earth and pointed north. An analog or digital computer determines the torque to be applied to the gyros, through a loop that is tuned using the Schuler pendulum principle. The necessary correction for earth rate depends on the position of the aircraft; the correction to be applied about the vertical axis depends on the velocity of the aircraft.

It is important that the stable element be accurately leveled with respect to the local vertical and aligned in azimuth with respect to true north. Precise leveling of the stable element is accomplished prior to flight by the accelerometers that

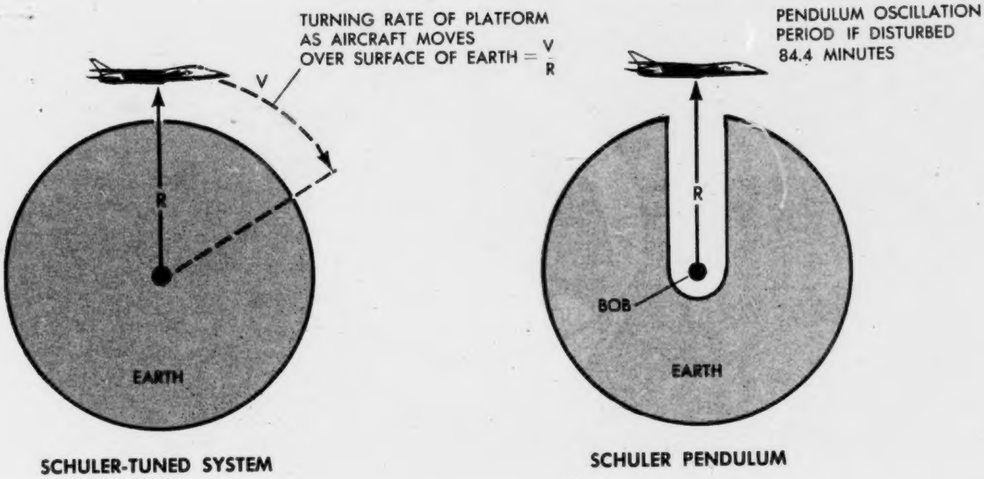


Figure 27-20. Schuler Pendulum Phenomenon

measure acceleration in the horizontal plane. The stable element is moved until the output of the accelerometers is zero, indicating that they are not measuring any component of gravity and that the platform is level.

Azimuth alignment to true north is accomplished before flight by starting with the magnetic compass output and applying variation to roughly come up with true north reference. From this point gyrocompassing is performed. This process makes use of the ability of the gyros to sense the rotation of the earth. If the stable element is misaligned in azimuth, the east gyro will see the wrong earth rate and will cause a precession about the east axis. This precession will cause the north accelerometer to tilt. The output of this accelerometer is then used to torque the azimuth and east gyro to insure a true north alignment and a level condition.

Solving Navigational Problem

The frame of reference of an inertial system will govern to some degree the uses of the system. The geographical coordinate system with north reference is the most common, but not the only system used. A north-oriented system requires that one accelerometer be mounted aligned to north and another mounted 90 degrees to the first, to sense east-west accelerations. This arrangement allows for any movement to indicate distance traveled east-west and north-south. Distance north-south is converted to coordinates by dividing miles traveled by 60 to obtain degrees; east-west travel requires that distance by multiplied by the secant of latitude and divided by 60 to obtain degrees. This is due to the convergence of meridians and is performed by computers. Although convenient, latitude and longitude reference has the distinct disadvantage of not being adaptable to use in the polar regions, because of convergence of latitudes. It is possible to offset the pole to a point on the equator. This offset would result in the polar areas being covered by a square grid. There is no specific reason to use a north-oriented system, for no external reference such as magnetic north is used in the inertial system. As a matter of fact, some inertial systems use a principle known as *Wander Angle,* which does not require the gyros to be oriented to true north. A wander angle inertial system has the advantage of being able to operate in polar regions.

The earth is not a perfect sphere but an ellipsoid, the equator diameter being 27 miles longer than the polar diameter. The inertial navigation system (INS) maintains a continuous local vertical reference and measures distance traveled over a reference spheroid which is perpendicular to the local vertical. This reference spheroid is mechanized by the I N S computer. On this spheroid, the latitude and longitude of the present position are continuously measured by the integration of ve-

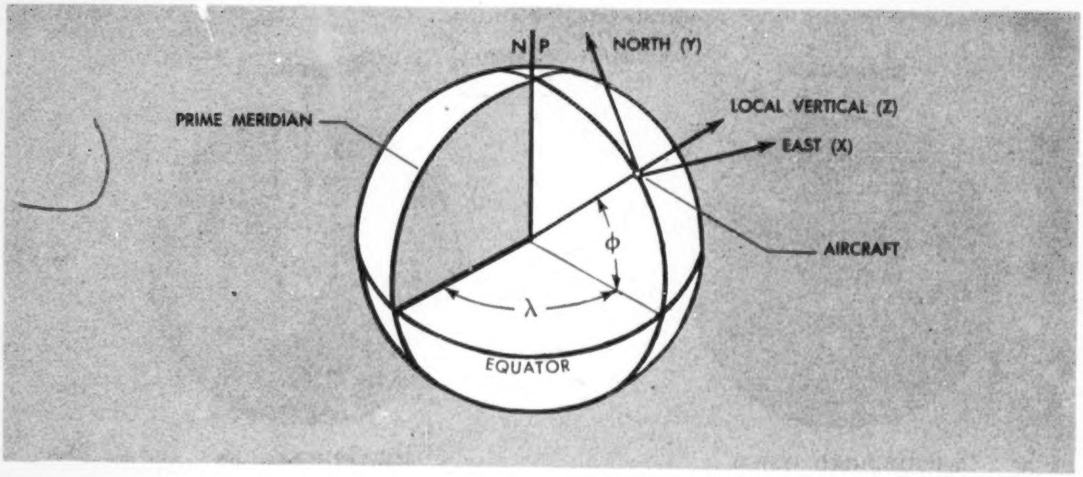


Figure 27-21. Geographic References

locity. In figure 27-21, phi represents latitude and lambda represents longitude.

The axes are arbitrarily designated X, Y, and Z—which correspond to east, north and local vertical respectively. This defines their positive directions. From now on reference to velocities, attitude angles, and rotation rates will be about the X, Y and Z axes. The local vertical (Z) is established by platform leveling. This is the most fundamental reference direction. To complete platform alignment, north (Y) must be known—this is accurately established by gyrocompassing. However, prior to gyrocompassing, the platform is course aligned—which is rotating the platform about the vertical (Z) axis through an angle equal to magnetic heading plus local variation, to an accuracy of .5 degrees or less. It should be pointed out here that gyrocompassing establishes platform alignment to the earth's axis of revolution or north pole. The I N S is capable of doing this to an accuracy of 10 minutes of arc or less. After the platform is aligned it remembers its alignment and always stays pointing to true north and the local vertical regardless of the maneuvers of the aircraft.

Groundspeed components of velocity in track (V), are measured by the system along the X and Y axes, as shown in figure 27-22. These components, Vx and Vy include all effects on the aircraft such as wind, thermals, engine accelerations, and speed brake decelerations. The groundspeed (V) is usually displayed by some form of digital readout.

The angles between the aircraft attitude and the platform reference attitude are continuously measured by synchros. The aircraft yaws, rolls, and pitches about the platform in a set of gimbals, each gimbal being rotated through some component of attitude. True heading is measured as the horizontal angle between the aircraft's longitudinal axis and platform north. This is shown in figure 27-23. Roll and pitch angles are measured by synchro transmitters on the platform roll and pitch gimbals.

Computer

Three of the basic components in any inertial navigation system—accelerometers, integrators and the stable element with its gyros—have been discussed. The fourth component is the computer.

The principle of inertial navigation does not include fixing enroute; thus, there is a need for much greater accuracy in the computers used with inertial than in those used with other systems. The computer function is less complex than that of basic GPI (ground position indicator) units. Since the input from the integrators is already defined as distance, the operation requires only the solution of present position. The second function of the computer is to send a positioning signal to the stabilized platform. Additional operations may

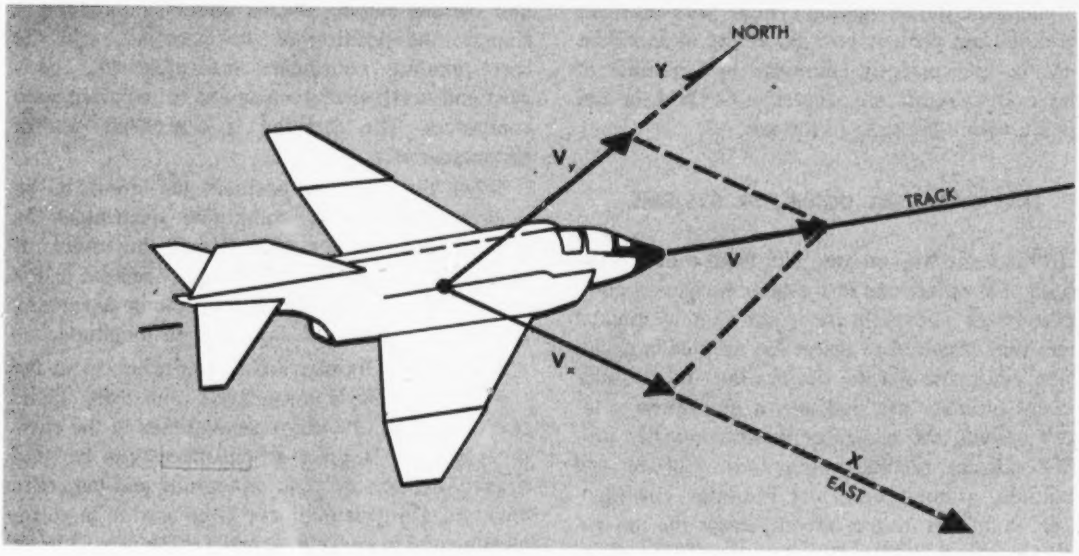

NORTH
Y
V_y
TRACK
V
V_x
X
EAST

Figure 27-22. Measurement of Aircraft Groundspeed

be performed by computers in selected units (solution and display of true headings, ground track, groundspeed, wind direction and velocity, etc.) but the two functions described are the only ones required of computers related to *all* inertial systems.

Summary

Inertial navigation system technology has advanced very rapidly within the past few years. Inertial is rapidly becoming the basic element around which advanced navigation systems are

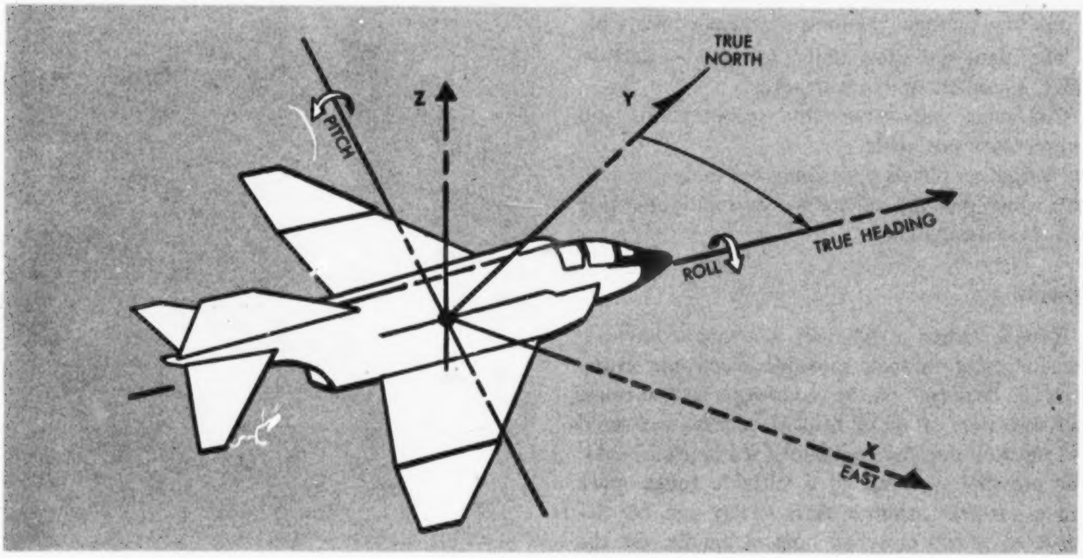

TRUE NORTH
Y
Z
PITCH
TRUE HEADING
ROLL
X
EAST

Figure 27-23. Measurement of Aircraft Attitude

designed. Inertial navigation systems with excellent reliability and present position errors of less than 3NM/hr are currently employed in a number of operational aircraft and accuracies of 1NM/hr and less are within the state of the art.

NAVIGATIONAL COMPUTER SYSTEMS

In the same way an autopilot frees a pilot from the manual operations of flying, a navigation computer system relieves the navigator of many manual operations required to direct the aircraft in flight. When automatic sensing devices like the Doppler and astrotracker are tied into a navigation computer system, the navigator is automatically provided current readings of present latitude and longitude, groundspeed, and heading. The navigation computer system thereby eases the navigator's work load and frees him to make the decisions that are beyond the capability of computers.

Modern aircraft are capable of speeds and ranges which require the navigator to perform extensive calculations rapidly and accurately. Consider a flight from the United States to a foreign country. The route could pass through areas of land, water, and ice caps. The navigator must contend with overcast, undercast, day, and night. He faces altitude changes, turning points, and mandatory ETA requirements. To handle all these conditions at the speed of sound or faster, the navigator uses automatic navigation computers.

The navigational computer system consists of:

- The data-gathering units (sensors) such as radar, Doppler, and astrotracker.
- Computer units where the computations and comparisons are made.
- Navigation panels containing the dials and controls which give the navigator a system monitoring and control capability.

Sensors

Radar. When a radar set is incorporated with the computer system, movable electronic crosshairs are displayed on the radarscope so that range and direction of radar returns can be measured and inserted into the computer (see figure 27-24). The crosshairs consist of a variable range mark and a variable azimuth mark. They can be maneuvered with a crosshair control handle. On the radarscope, they resemble a single fixed range mark and a heading mark. By moving the crosshair control handle, the navigator simultaneously changes the position of the crosshairs and the corresponding coordinate measurements (east-west and north-south) being fed to the navigation computers. The function is completed almost instantaneously.

When the navigator positions the crosshairs on a given return, the computers determine the distance between the aircraft and the return. If the coordinates of the return have been set in the computer, the computer can maintain a running account of the aircraft latitude and longitude.

Doppler. Doppler radar's contribution to the computer system is groundspeed and drift. These two outputs can be put to several uses in the computer system. Doppler groundspeeds can be used to drive the present position latitude and longitude counters. Doppler outputs can be used in platform leveling and in checking inertial groundspeed in an inertial system. Doppler radar is an essential part of many navigation computer systems.

Astrotracker. The astrotracker is another data-gathering unit in a computer system. Its accurate measurement of true heading regardless of local magnetic variation makes the astrotracker a valuable addition. The navigation computer

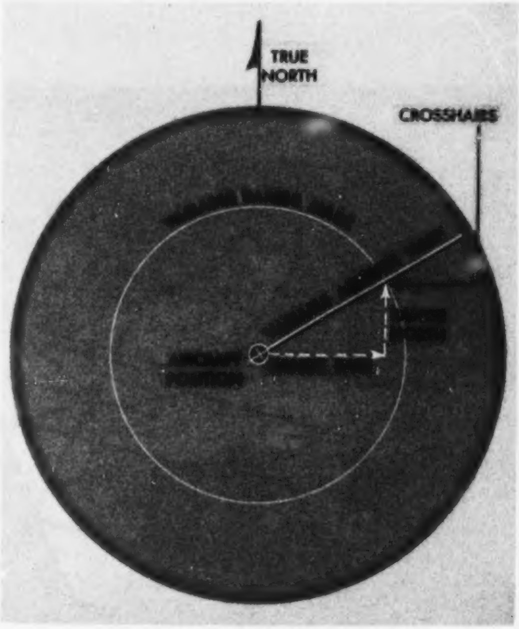


Figure 27-24. Radar Crosshairs

system can combine astrotracker true heading with Doppler drift to produce current aircraft track. The astrotracker also provides celestial LOP information which can be used by the navigation computer for fixing.

INERTIAL NAVIGATION. The inertial unit is used to feed velocity information into the computers. Once the inertial sensor is leveled and in operation, it is used to update continually the present position counters.

LORAN-C. Loran-C, discussed in chapter 21, fits well in an automatic computer system. Some computer systems have the coordinates of Loran stations stored in them; during flight, the navigator selects the stations he wants to use and the computer does the rest. Fixing is automatic and occurs in somewhat the same way that a navigator takes a celestial fix. An assumed position is determined by the computers; the Loran position is then applied to this assumed position. A series of credibility checks and approximations are applied automatically by the computer. The result is an accurate Loran fix. When the computers function in the Loran mode, continuous present position and groundspeed information is still available.

TACAN. TACAN can be easily added to a computer system. Since the TACAN output is given in the form of a range and bearing, the computers need only the coordinates of the TACAN station being used. This data can be set into the computers before the mission begins. Some corrections must be applied to TACAN outputs to increase accuracy. The bearings received from TACAN are magnetic; therefore, the computer must have an accurate magnetic variation value at all times. This is usually built into the computer. TACAN range output is expressed in slant range. The computer applies absolute altitude above the station to the slant range to produce exact ground range.

Computer Unit

The two basic types of navigation computers most used are the analog and the digital.

ANALOG. An analog computer is comparable to the navigator's hand-held computer in that a graphic replica of the problem to be solved is constructed in order to find the answer. The analog computer is generally larger than the digital computer, partially because many components must be added to solve a wide variety of problems. Some of these computers weight as much as 2,000 pounds. The analog computer has one main advantage, it is not as sensitive to temperature and pressure changes as the digital system.

DIGITAL. The digital computer is generally lighter and more compact than the analog system. In some cases, the digital computer weighs less than 100 pounds. It computes navigation problems in a much different manner than does the analog computer. It is unnecessary to design a digital computer expressly for the navigation problems it is to solve. Properly programmed, the same computer could be used in fields other than navigation. This is possible because the digital computer deals strictly with numbers. This requires that all inputs be changed to a numerical value before they are sent to the computer. All outputs likewise must be converted back to terms which are meaningful to the navigator.

DETERMINING POSITION. Regardless of computer type, the problems to be solved by a navigation computer remain the same. The ever-present problem facing the navigator is determination of aircraft position. With a computer system, it is not necessary to estimate a position based on a track and groundspeed derived from the last known position. The computer always displays the current position for convenient reading.

Example.

Figure 27-25 illustrates an example which depicts determination of present position using astrotracker and Doppler information.

The astrotracker sends a true heading of 040° to the computer and the Doppler registers groundspeed of 707 knots and drift of 5° right. The true heading and drift are combined in the computer to produce a value of track; in this case, 045°.

The groundspeed can be resolved around the direction of track to produce values of groundspeed to drive the latitude and longitude counters. In this case, the groundspeed north and east is 500 knots. Though this process seems basically simple, a few corrections must be applied to the groundspeed components before they are sufficiently accurate for present position drive. These corrections, done within the computer, include such things as compensation for convergence of meridians and for the imperfect shape of the earth.

DETERMINING HEADING TO DESTINATION. Another question the navigator often faces is,

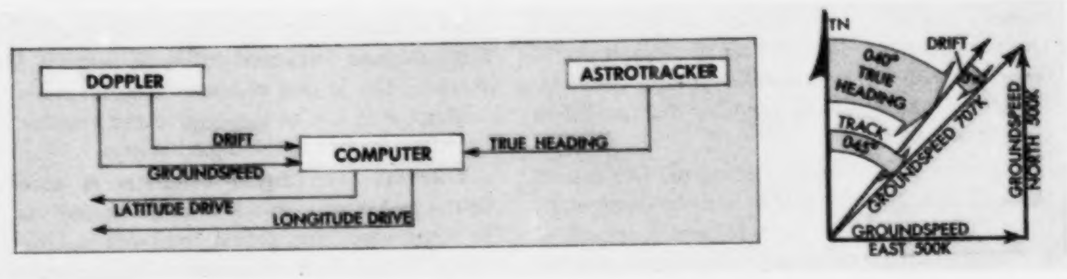


Figure 27-25. Present Position Counter Drive

"What is the heading to destination?" This question is also answered by many navigation computer systems. The computer first computes the required track, either rhumb line or great circle. To do this, it computes the direction and distance from the present latitude and longitude to the destination latitude and longitude. The present track, taken from the inertial system in this instance, is then compared to the required course to destination; the difference is a heading correction. Groundspeed may be applied to the distance to destination, and a time-to-go may be computed to provide a continuous ETA.

Navigation Panels

The navigation panels comprise the greatest part of the computer system visible to the navigator. Panel appearance and operation vary with each computer system. The multitude of counters, dials, switches, buttons, control knobs, and selectors give the navigator maximum use and control of the system. Selectors that determine which sensors will be used and which read-outs will be given, permit the navigator to switch from one mode of operation to another.

The computer system aids the navigator in other ways. Most modern computers have limits built into them so they will not accept unreasonable information. For instance, if the coordinates of a fix point are set one degree of latitude in error, the computer rejects the fix because the information is totally incompatible with information already in the computer. A rapid change in groundspeed from a sensor might be rejected and that sensor output no longer used because it would be considered unreliable.

So far in this discussion, only basic navigation has been considered. A sophisticated computer system can solve ballistic problems and automatically release bombs and missiles. If the system is installed on a transport type aircraft, cargo drops and notification of bailout time to paratroops can be controlled by the navigation computer.

All computer systems do not contain all the sensors or have all the capabilities described above. The mission requirements of the aircraft dictate what the computer system should comprise. With advancements in science and engineering, automatic computer systems will have increased capabilities and uses. The systems will become lighter and more compact thereby increasing the practicability of installing them on more aircraft.

SUMMARY

While all the automatic navigation systems in use today appear to spell complexity, they have been designed to assist the navigator with the myriad of navigation problems associated with high speed aircraft. Each system is relatively simple to operate and provides its information as a part of the overall navigation problem. The use of Dopplers, astrotrackers, inertial systems, and navigation computers which combine these inputs into the solution of this overall problem serve to simplify and reduce the tasks of the navigator.

CHAPTER 28

Aerial Delivery

INTRODUCTION

Placing a weapon on the target, aerial delivery of troops and supplies, or a photo reconnaissance mission require many of the same techniques. Typical mission profiles consist of high altitude flights to the general target area, then a descent, and a low altitude flight to the target so as to avoid enemy detection and defenses. Timing on the low altitude portion of many aerial delivery missions is critical, and precise arrival over the target or drop zone must be carefully planned and executed. The methods used to control timing are discussed in chapter 25.

The low altitude portion of the mission can be used to advantage in updating ballistics or Computed Air Release Point (CARP) information. as well as for turning on or rechecking camera equipment for a photo reconnaissance mission.

The solution of the ballistics for a bomb drop or the CARP for an aerial delivery requires similar data and methods of solution. Examination of the problem shows that locating the proper point in space from which to release is, in theory, a simple airplot problem. Any object dropped from an aircraft is affected by certain factors. Among these are aircraft airspeed, altitude above the target, air resistance upon the object being dropped, and wind effect. In photo reconnaissance, drift of the aircraft and altitude are significant in establishing the aircraft on the true heading so that the cameras are properly aligned to accomplish the mission.

Sophisticated computers have been designed that greatly simplify locating the release point. However, the navigator must still insure that his timing and adherence to a preplanned route of flight to this release point are maintained. These, too, are important factors in a successful aerial delivery.

THE BOMBING PROBLEM

Precision bombing is the heart of the bombardier's profession. Quite literally, success as a navigator is measured in miles and minutes, but success as a bombardier is measured in feet and seconds, often fractions of seconds. The navigator rounds off many values and still turns out a first-rate job; the nature of the bombing problem forces the bombardier to observe exacting tolerances and eliminates the margin for guesswork. The first step to understanding the bombing problem is consideration of some of the factors that affect the bomb's trajectory.

Governing Factors

- Gravity pulls the bomb toward the earth.
- Air Resistance opposes the downward and forward movement of the bomb. Air resistance causes the bomb to lag behind the aircraft after release. This is referred to as *trail*.
- Bombing altitude, the higher the altitude, the more time it takes for the bomb to fall. This is known as *Actual Time of Fall* (ATF).
- True airspeed imparts forward motion to the bomb. The amount of trail increases as airspeed increases.
- Wind effect, combined with airspeed and heading, establishes the ground path of the bomb. Wind requires that the bomb be released upwind of the impact point.

Bomb-Nav System

These factors are mathematically resolved in the Bomb-Nav System (BNS) computers to solve for what is technically termed the Bomb Resolver Locus (BRL). This is the computed air position

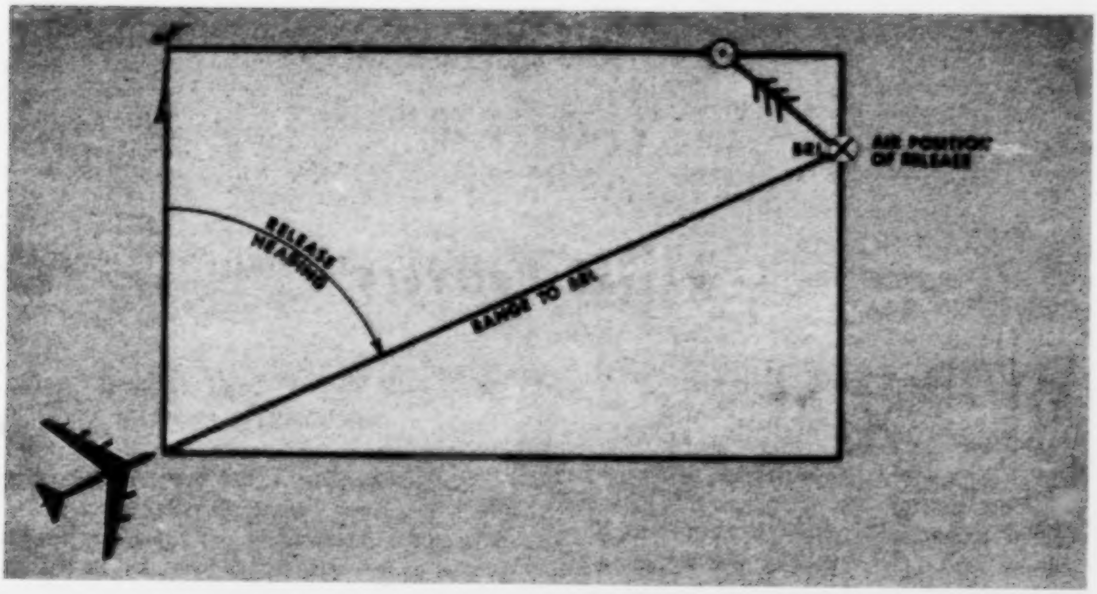

RELEASE HEADING
RANGE TO SRL
SRL
AIR POSITION OF RELEASE

Figure 28-1. Horizontal Bombing Problem

of the target. It is located upwind of the target by the amount of wind effect. Also computed by the BNS is the correct release heading of the aircraft and the time the weapon is to be released.

The bombing problem can be viewed in two planes, horizontally and vertically, but both planes are solved simultaneously in the BNS. See figures 28-1 and 28-2.

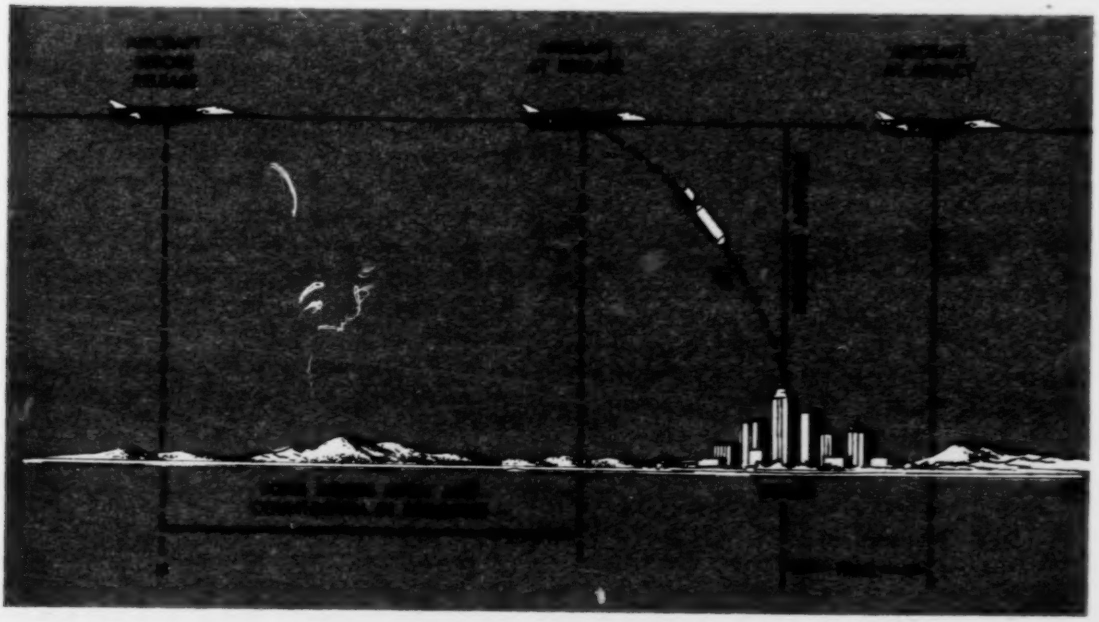


Figure 28-2. Vertical Bombing Problem

To determine the release heading, the BNS must be able to locate the target to determine wind effect on the bomb. By placing the crosshairs (electronically generated signal on the radarscope) on a radar return, the operator identifies the target for the BNS. By resolving for wind effect on the bomb against time-to-go to impact, the BNS provides release heading and range to the Bomb Resolver Locus.

Vertical Problem

The vertical problem is concerned with establishing the *time of release*. To determine the exact time of release, two things must be known: how long the weapon will be in the air from release until impact, and how far away in time the weapon is from the target. Released too soon, the bomb falls short; released too late, the bomb falls beyond the target. The time from release to impact is taken from ballistics tables and set into the computer. Because of the shape and size of a bomb and delivery with or without a chute, separate tables are consulted for each type bomb. The system then computes the time remaining to impact when the crosshairs are placed on the target.

To illustrate a typical bomb run, the bombardier places his crosshairs on the aiming point and sets his bomb computers into operation. The pilot centers the directional indicator that aligns the aircraft on the computed heading for release, and gives the bombardier steering control of the aircraft via an autopilot hookup. The bombardier checks true airspeed and altitude to assure that the ballistics settings are still correct. At some value of range, depending upon the BNS in use, the timing meter will start; this provides the countdown to bomb release. While the bombardier appears to be merely keeping his crosshairs on the aiming point, he is actually furnishing the BNS with all the inputs needed to solve the bombing problem. At five seconds to go, the bomb doors open; at "bombs away" a signal is sent to the release circuits and the weapons are dropped. Steering of the aircraft is again turned over to the pilot for return to home base. Whether the bomb is delivered by a B-52 or an F-4, the principles are the same and the bombing problem is solved in a similar manner by computers.

COMPUTED AIR RELEASE POINT

The Computed Air Release Point system is the standard tactical drop system. Commonly referred to as a CARP, it is a scientific approach to a parachute bombing problem. Mathematical in nature, a CARP is based on average parachute ballistics and fundamental dead reckoning principles.

Aircraft commanders are responsible for insuring that a CARP solution is computed and used in all parachute operations not using a ground-marked or electronic release point; however, the navigator is responsible for the actual solution of the CARP (figure 28-3). The pilot and the navigator jointly confirm the offset distance for the CARP. The pilot assumes the responsibility for maintaining the offset distance and required track. The navigator picks the timing point, controls the time to release, and continually crosschecks the offset distance. Both pilot and navigator must have complete cooperation and teamwork.

Governing Factors

CARP is primarily concerned with the point of impact of the first parachute-supported object. The actual ground pattern of the remaining airdropped personnel and/or equipment depends upon:

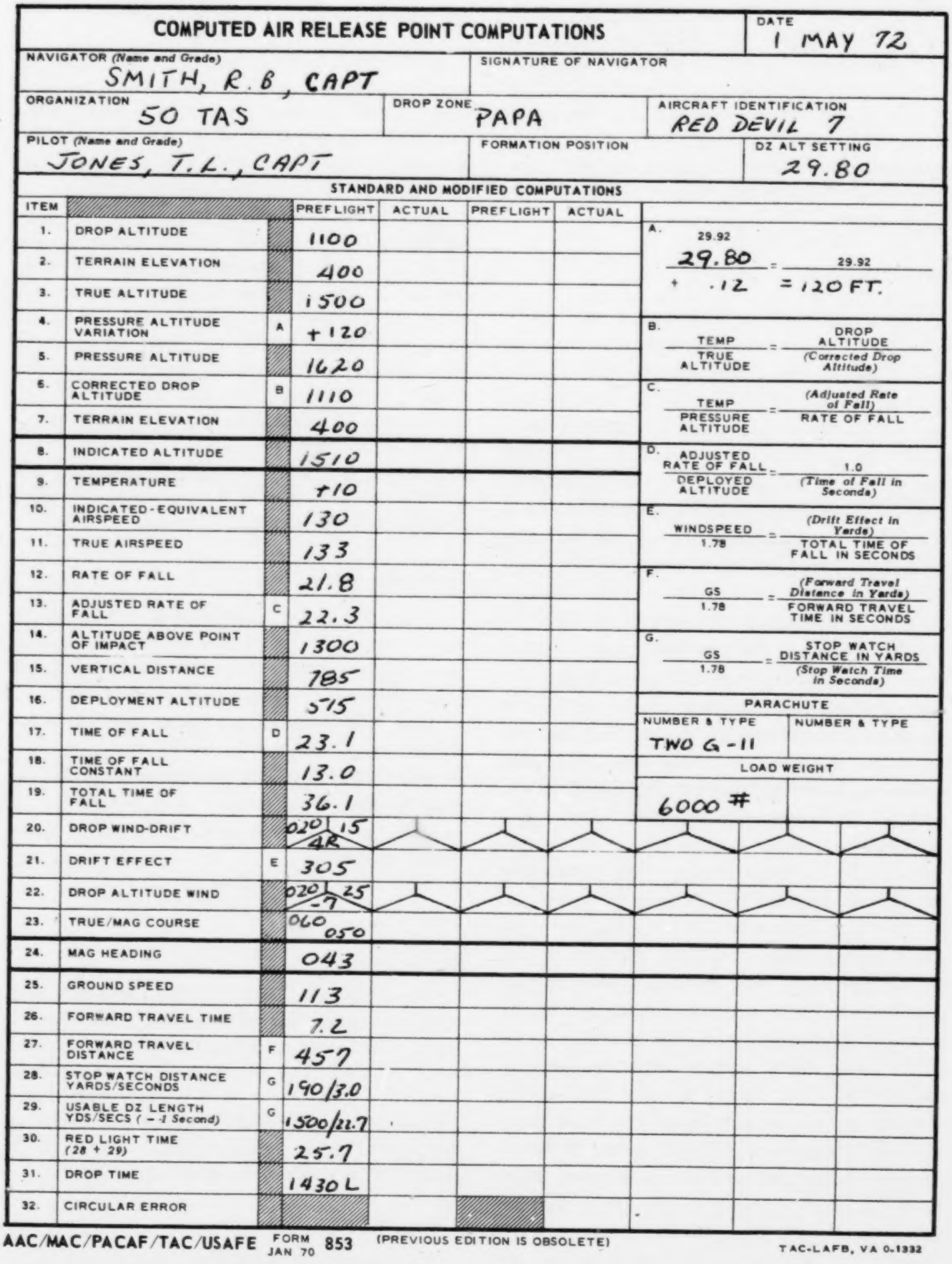
- Time lapse between the initial signal to jump or eject cargo, and the time of last exit.
- Aircraft stability from the computed air release point throughout the jump or ejection period.
- Uniformity of loads and/or parachute types within elements.
- Glide angle of individual parachutes.
- Aircraft track along the drop zone.

Initial Point (IP)

The initial point must be chosen with care and must be a prominent yet a relatively small checkpoint, and should be located a sufficient distance from the drop zone to allow slowdown to drop airspeed, performance of slowdown maneuvers, and for any respacing of formation that might be required. The IP should be located as close as possible to the axis of the drop zone (DZ).

Timing Points

The location of the timing point should be as close as possible to the release point. It is difficult to position an aircraft exactly over a small



COMPUTED AIR RELEASE POINT COMPUTATIONS

DATE: 1 MAY 72

NAVIGATOR (Name and Grade): SMITH, R.B, CAPT

SIGNATURE OF NAVIGATOR:

ORGANIZATION: 50 TAS

DROP ZONE: PAPA

AIRCRAFT IDENTIFICATION: RED DEVIL 7

PILOT (Name and Grade): JONES, T.L., CAPT

FORMATION POSITION:

DZ ALT SETTING: 29.80

STANDARD AND MODIFIED COMPUTATIONS

ITEM	▨		PREFLIGHT	ACTUAL	PREFLIGHT	ACTUAL
1.	DROP ALTITUDE	▨	1100			
2.	TERRAIN ELEVATION	▨	400			
3.	TRUE ALTITUDE	▨	1500			
4.	PRESSURE ALTITUDE VARIATION	A	+120			
5.	PRESSURE ALTITUDE	▨	1620			
6.	CORRECTED DROP ALTITUDE	B	1110			
7.	TERRAIN ELEVATION	▨	400			
8.	INDICATED ALTITUDE	▨	1510			
9.	TEMPERATURE	▨	+10			
10.	INDICATED-EQUIVALENT AIRSPEED	▨	130			
11.	TRUE AIRSPEED	▨	133			
12.	RATE OF FALL	▨	21.8			
13.	ADJUSTED RATE OF FALL	C	22.3			
14.	ALTITUDE ABOVE POINT OF IMPACT	▨	1300			
15.	VERTICAL DISTANCE	▨	785			
16.	DEPLOYMENT ALTITUDE	▨	515			
17.	TIME OF FALL	D	23.1			
18.	TIME OF FALL CONSTANT	▨	13.0			
19.	TOTAL TIME OF FALL	▨	36.1			
20.	DROP WIND-DRIFT	▨	020 15 4R			
21.	DRIFT EFFECT	E	305			
22.	DROP ALTITUDE WIND	▨	020 25 -7			
23.	TRUE/MAG COURSE	▨	060 050			
24.	MAG HEADING	▨	043			
25.	GROUND SPEED	▨	113			
26.	FORWARD TRAVEL TIME	▨	7.2			
27.	FORWARD TRAVEL DISTANCE	F	457			
28.	STOP WATCH DISTANCE YARDS/SECONDS	G	190/3.0			
29.	USABLE DZ LENGTH YDS/SECS (− 1 Second)	G	1500/22.7			
30.	RED LIGHT TIME (28 + 29)	▨	25.7			
31.	DROP TIME	▨	1430 L			
32.	CIRCULAR ERROR	▨	▨		▨	

A.
29.92
29.80 = 29.92
+ .12 = 120 FT.

B. $\frac{\text{TEMP}}{\text{TRUE ALTITUDE}} = \frac{\text{DROP ALTITUDE}}{\text{(Corrected Drop Altitude)}}$

C. $\frac{\text{TEMP}}{\text{PRESSURE ALTITUDE}} = \frac{\text{(Adjusted Rate of Fall)}}{\text{RATE OF FALL}}$

D. $\frac{\text{ADJUSTED RATE OF FALL}}{\text{DEPLOYED ALTITUDE}} = \frac{1.0}{\text{(Time of Fall in Seconds)}}$

E. $\frac{\text{WINDSPEED}}{1.78} = \frac{\text{(Drift Effect in Yards)}}{\text{TOTAL TIME OF FALL IN SECONDS}}$

F. $\frac{\text{GS}}{1.78} = \frac{\text{(Forward Travel Distance in Yards)}}{\text{FORWARD TRAVEL TIME IN SECONDS}}$

G. $\frac{\text{GS}}{1.78} = \frac{\text{STOP WATCH DISTANCE IN YARDS}}{\text{(Stop Watch Time in Seconds)}}$

PARACHUTE

NUMBER & TYPE	NUMBER & TYPE
TWO G-11	
LOAD WEIGHT	
6000 #	

AAC/MAC/PACAF/TAC/USAFE FORM JAN 70 853 (PREVIOUS EDITION IS OBSOLETE) TAC-LAFB, VA 0-1332

Figure 28-3. Computations for Computer Air Release Point

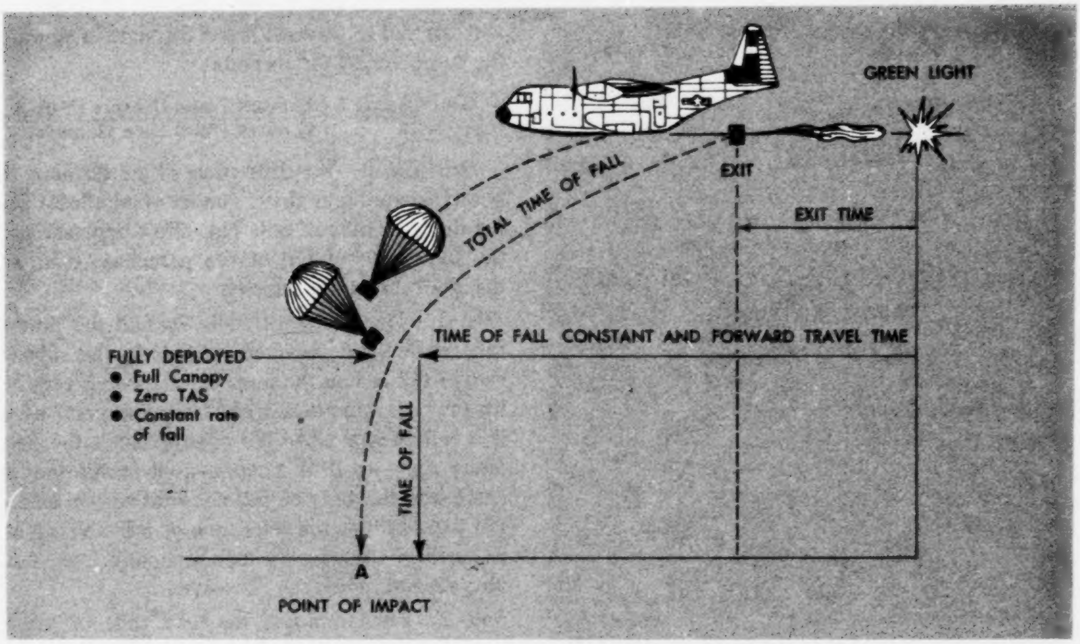


Figure 28-4. CARP Time Diagram

geographical checkpoint without some type of sighting device; therefore, for precision dropping, timing points should be used to determine when the aircraft has reached the computed air release point. When the computed air release point falls abeam a small, easily recognizable checkpoint, a timing point is unnecessary.

During daylight VFR conditions, the timing point is selected after computing and plotting the air release point. This timing point must be visible as the aircraft passes it, yet be as close to course as possible so that an accurately timed run can be made to the CARP.

For night operations or low visibility conditions, two timing points should be chosen prior to takeoff and marked by the combat control team. These timing points should be located equidistant from the designated point of impact back along the approach axis of the drop zone. The exact location of these timing points must be known by each crewmember.

Parachute Ballistics

The ballistics of different types of parachutes vary. Each parachute has been designed for a specific purpose and has its own peculiar characteristics. Personnel parachute ballistics are the most accurate as they open rapidly and are deployed by a static line of specified length. The parachute ballistics used in the solution of the CARP system for forward travel time and vertical distances are averages which are accurate enough to warrant their use on airdrops.

One important ballistic of parachutes, which is not considered in CARP and which cannot be taken into consideration in any parachute delivery technique, is the gliding characteristics of each parachute. A parachute glides in many different directions during its descent and these different directions tend to cancel out. If this were not the case, it would be extremely difficult to obtain the desired accuracy, even if other variables (such as wind effect and aircraft positioning) were negligible. For example, the T-10 parachute has a gliding angle of 18 degrees from the vertical. This gliding effect of the parachutes is what makes them appear to drift under no-wind conditions.

Components

Vertical Distance—the distance in feet the parachute and load fall during the deceleration time.

Rate of Fall—the rate of fall expressed in feet

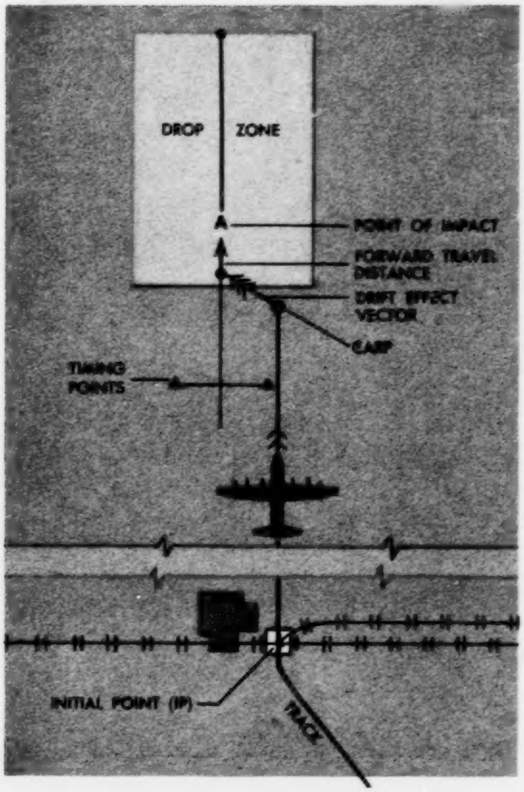


Figure 28-5. CARP and DZ Diagram

per second of each particular parachute after it has become completely deployed as governed by the combined weight of the parachute and load. This rate of fall becomes the adjusted rate of fall when corrected for nonstandard temperatures.

Time of Fall Constant—the elapsed time from exit of the load until full deployment of the parachute minus a constant to compensate for the reduced forward speed and increased drift during the deceleration period.

Forward Travel Time—the time from green light (signal for release) to exit of the parachutist or equipment/supply bundle from the aircraft plus a deceleration constant to compensate for the reduced forward speed and the deceleration period. (See figure 28-4.)

Forward Travel Distance—the distance along the track of the aircraft that the load travels from green light to full deployment. The forward travel time must be multiplied by groundspeed to obtain this distance. The forward travel time in seconds is converted to forward travel distance in yards on the computer by the formula:

$$\frac{\text{Groundspeed}}{1.78} = \frac{\text{Forward Travel Distance (Yards)}}{\text{Forward Travel Time (Seconds)}}$$

Drift Effect—the drift effect is the distance the parachute and load drifts (under wind effect) during the total time of fall. This effect depends upon the total time of fall of the parachute load and the wind direction/velocity.

Step 1. Total Time of Fall. To find the time of fall, divide the deployment altitude by the adjusted rate of fall to find the number of seconds required for the parachute to descend from that point where it is fully deployed to the ground. Since the parachute starts to drift as soon as it leaves the aircraft, add the time of fall constant to the time of fall to determine the total time of fall which is the number of seconds the load is falling free of the aircraft and affected by the wind.

Step 2. Then multiply the total time of fall by the wind velocity to find the wind effect. The formula is:

$$\frac{\text{Wind Speed}}{1.78} = \frac{\text{Drift Effect (Yards)}}{\text{Total Time of Fall (Seconds)}}$$

Plotting CARP—the forward travel distance and drift effect have been discussed in the sequence in which they occur; however, the CARP is plotted as follows:

Step 1. Starting from the point of impact, plot the forward travel distance back along the DZ axis.

Step 2. Plot the drift effect upwind from the end of the forward travel vector. The end of the drift effect vector is the CARP (figure 28-5).

PHOTO RECONNAISSANCE

Tactical photo reconnaissance provides most, if not all, of the pre-strike and post-strike photos of enemy troops and supplies, staging areas, behind-the-line enforcements, and the results of previous air and ground strikes against the enemy. The capability of the RF-4 to photograph moving targets is legendary and made possible by ultra-sophisticated sensor systems. These reconnaissance sensors include optical cameras for day or night photography using flash cartridges, side-looking radar which affords the capability for recording moving vehicles several miles away, and

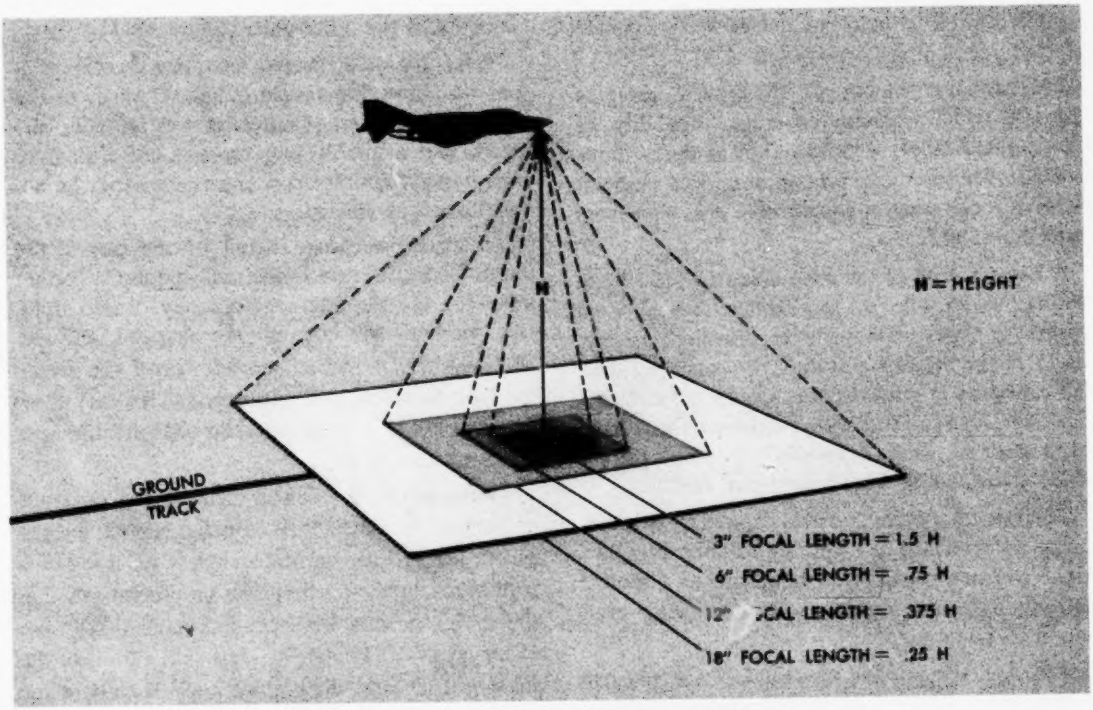

H
H = HEIGHT
GROUND TRACK
3" FOCAL LENGTH = 1.5 H
6" FOCAL LENGTH = .75 H
12" FOCAL LENGTH = .375 H
18" FOCAL LENGTH = .25 H

Figure 28-6. Night Photography (Pinpoint)

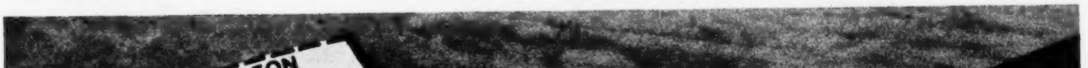

HORIZON
H
GROUND TRACK
FORWARD-OBLIQUE
LOW PAN
HORIZON
OPTICAL
IR

Figure 28-7. Multi-Sensor Low Altitude Profile (Camera Area Coverage)

infrared sensors which can detect even a single vehicle under a jungle canopy.

The primary sensors are the optical cameras which provide a varied coverage capability of many square miles; a mosaic shot at thirty thousand feet for surveying a large area or a pinpoint photo of a one-quarter square mile area shot from three thousand feet.

A camera such as the nose-mounted KS-87 can be fitted with one of four different lens focal lengths to photograph an area equivalent to one-fourth of the aircraft altitude up to one and one-half times the aircraft altitude (figure 28-6). Flying at ten thousand feet with a three-inch lens focal length camera, each frame will produce a picture fifteen thousand by fifteen thousand feet.

The optical system has the capability of processing its own film in flight, so that the film cartridge can be dropped via parachute to a remote outpost, providing instantaneous intelligence evaluation of the target area.

To provide complete coverage of the selected targets, three cameras may be used simultaneously. Infrared sensors are used in conjunction with these cameras to spot objects not seen by the eye or recorded by the cameras. A typical arrangement for a low-level run would include a nose-mounted camera which is aligned along the track of the aircraft, a centrally mounted horizon-to-horizon panoramic camera that provides photography beneath and to the side of the aircraft, and two oblique cameras which produce images of the same general area but which will function also as a backup for the other units (figure 28-7).

While this setup allows planning flexibility, it does not allow for simple inflight changes to the mission parameters. Predetermined altitude, airspeed, and available film footage are critical to each mission and the run must necessarily be accomplished as briefed.

To assure adequate detail of the target, the photo intelligence personnel will request a certain scale for the required photography. Based upon this, the crew will compute the airspeed, altitude, and number of feet of aircraft travel per frame exposed to arrive at a requirement for film footage. One mission alone can require as much as one thousand feet of film.

The problem of assuring location and coverage of targets in daylight is usually solved by the pilot's use of the viewfinder; but when using cartridges to illuminate the target on a night mission, the navigator must be depended upon to fully use every bit of his knowledge and skill. To eject the flash cartridges at the correct interval to light the target, the Initial Point must be made good with split-second timing, the altitude cannot vary nor can the speed of the aircraft or the cartridges will fire sooner or later than the exact moment of target passage, and the mission will be something less than successful. Crew coordination deserves emphasis here, and as on any critical and highly demanding mission, the professional approach to the problem is the only method that will guarantee first-class photo intelligence results.

BY ORDER OF THE SECRETARY OF THE AIR FORCE

OFFICIAL

JOHN D. RYAN, *General, USAF*
Chief of Staff

JACK R. BENSON, *Colonel, USAF*
Director of Administration

BY DIRECTION OF THE COMMANDER, NAVAL AIR SYSTEMS COMMAND

Summary of Revised, Deleted, or Added Material

All material has been updated and expanded to permit quick reference to specific information and inclusion of new material by changes, and to incorporate the most recent information on principles and procedures of various types of navigation. Detailed information on specific equipment which is subject to frequent change is not included. Added new chapter 28, Aerial Delivery.

ATTACHMENT 1

Symbols

━━━━━━	Course line
——>——	True heading
——>>——	Track
——>>>——	Wind vector
<————>	LOP or PLOP
<<————>>	LOP or PLOP (advanced or retarded)
◀————▶	Average LOP or PLOP
⊙	DR position or true sun
△·	Fix
△L	Loran fix
△R	Radio fix
△M	Map reading fix
△V	Radar fix
△C	Celestial fix
⊙ MPP	Most probable position
+	Air position
⋀	Assumed position
♈	Vernal equinox — First point of Aries
✓	No change from previous log entry
⊕	Departure and Destination

ATTACHMENT 2

Abbreviations

A

AA	absolute altitude
A/C	alter course, aircraft, aircraft commander
ADC	automatic drift control
ADF	automatic direction finder
AF	audio frequency
AFC	automatic frequency control
A/H	alter heading
alt	altitude
AM	amplitude modulation, ante meridian
ant	antenna
AP	airplot, air position, assumed position
API	air position indicator
ARA	airborne radar approach
ARTCC	Air Route Traffic Control Center
AS	airspeed
ATA	actual time of arrival
ATC	Air Traffic Control
ATF	actual time of fall
AVC	automatic volume control
AWS	Air Weather Service
az	azimuth

B

BAS	basic airspeed
BAT	basic air temperature
BD	Bellamy drift
BFO	beat frequency oscillator
BMT	beginning of morning twilight
BNS	bomb-nav system
BPA	basic pressure altitude
BRL	bomb resolver locus
BTA	basic true altitude

C

CAS	calibrated airspeed
CCW	counterclockwise
CDI	course deviation indicator
CF	Coriolis force
CFP	computer flight plan
CH	compass heading
Cl	climb
cm	centimeter
comp	computer, compass
corr	correction, corrected
CPC	constant pressure chart
CRT	cathode ray tube
CW	clockwise, continuous wave

D

"d"	correction to tabulated altitude for minutes of declination
D	D-soundings, difference between TA and PA
D_1, D_2, etc.	successive D readings
DA	density altitude, drift angle
DAS	density airspeed
DC	drift correction
DCA	drift correction angle
DD	double drift
Dec	declination
dept	departure
dest	destination
dev	deviation
DF	direction finder
DG	directional gyro
DH	desired heading
DMAAC	Defense Mapping Agency Aerospace Center
DME	distance measuring equipment
DR	dead reckoning
DZ	drop zone

E

E	east, error
EAD	effective air distance
EAP	effective air path
EAS	equivalent airspeed
EET	end of evening twilight
ETA	estimated time of arrival
ETAS	effective true airspeed
ETP	equal time point

F

FAA	Federal Aviation Agency
FAR	Federal Air Regulations
FH	final heading

FIO	Flight Information Office
FIR	Flight Information Regions
FLIP	Flight Information Publications
FM	frequency modulation
FSS	Flight Service Station

G

G	acceleration caused by gravity
GAT	Greenwich apparent time
GC	grid course
GCA	ground controlled approach
GEOREF	World Geographic Reference System
GH	grid heading
GHA	Greenwich hour angle
GMT	Greenwich mean time
GN	grid north
GP	gyro precession
GPI	ground position indicator
griv or GV	grid variation, grivation
GS	groundspeed
GST	Greenwich sidereal time

H

H	altitude, height, high
Hc	computed altitude (celestial)
HF	high frequency (3,000-30,000 kHz)
Hg	mercury
Ho	observed altitude
Hp	precomputed altitude (celestial)
Hs	sextant altitude (celestial)
Hz	cycles per second

I

IAS	indicated airspeed
IAT	indicated air temperature
ICAO	International Civil Aviation Organization
IF	intermediate frequency
IFF	Identification Friend or Foe
IFR	Instrument Flight Rule
IH	initial heading
ILS	instrument landing system
ind	indicated
INS	inertial navigation system
intcp	intercept
IP	initial point, identification of position
IPA	indicated pressure altitude
ITA	indicated true altitude

J-K

k	knots
K	constant
kHz	kilocycles (1000 cycles) per second
km	kilometer

L

L	low
lat	latitude
LAT	local apparent time
LCT	local civil time
LF	low frequency (30-300 kHz)
LHA	local hour angle
Lm	midlatitude
LMT	local mean time
Ln	loran
L.O.	level off
long	longitude
LOP	line of position
LOS	line of sight
L-R	left-right
LST	local sidereal time

M

m	meter
M	moment, Mach number
mb	millibar
MB	magnetic bearing
MC	magnetic course
MC&G	mapping, charting, and geodetic
MF	medium frequency (300-3000 kHz)
MGRS	Military Grid Reference System
MH	magnetic heading
mHz	megacycles per second
mm	millimeter
MN	magnetic north
mph	miles per hour
MPP	most probable position
ms	microseconds
MSL	mean sea level

N

N	north, nadir
NDB	non-directional beacon
NM	nautical miles
NMC	National Meteorological Center

O

OAT	outside air temperature

P

PA	pressure altitude, parallax
PAV	pressure altitude variation
PCA	positive control area
PGF	pressure gradient force
PLOP	pressure line of position
PM	pulse modulation, post meridian
pos	position
PPI	plan position indicator
pps	pulses per second
PR	position report
PRF	pulse recurrence frequency
PRR	pulse recurrence rate
PRT	pulse recurrence time
PW	pulse wave

Q

Q	correction applied to Ho of Polaris

R

r	radius
R	refraction
RB	relative bearing
RF	radio frequency
RMI	radio magnetic indicator
R/T	receiver/transmitter

S

S	south, speed
SD	semidiameter
SDC	single drift correction
sext	sextant
SHA	sidereal hour angle
SID	standard instrument departure
SIF	selective identification feature
SSB	single sideband
STC	sensitivity time constant

T

TA	true altitude
TAMPA	true altitude minus pressure altitude
TAR	terrain avoidance radar
TAS	true airspeed
TAT	true air temperature
TB	true bearing
TC	true course
TCA	terminal control area
temp	temperature
tgt	target
TH	true heading
TN	true north
TO	takeoff
TP	turning point
Tr	track
T/R	transmitter/receiver

U

UHF	ultra high frequency (300-3000 mHz)
UIR	Upper Information Region
UPS	Universal Polar Stereographic
UTM	Universal Transverse Mercator

V

var	variation, variable
VFR	Visual Flight Rule
VHF	very high frequency (30,000-300,000 kHz)
VLF	very low frequency (below 30 kHz)
VOR	VHF omnidirectional range (omnirange)
VRM	variable range marker

W

W	west
WAC	World Aeronautical Chart
WD	wind direction
WS	wind speed
W/V	wind velocity, wind vector

X-Y-Z

Z	azimuth angle
ZD	zenith distance, zone difference
Zn	true azimuth
ZN	pressure pattern displacement
ZT	zone time

ATTACHMENT 3

Explanation of Terms

ABSOLUTE ALTIMETER—An instrument designed to indicate the actual height of an aircraft above the terrain. It works on the principle of measuring the time interval between transmission of a signal and the return echo from the earth's surface, or by measuring the phase difference between the transmitted signal and echo.

AGONIC LINE—A line on a chart joining points of no magnetic variation.

AIR ALMANAC—A joint publication of the US Naval Observatory and British Royal Observatory covering a four-month period. It contains tabulated values of the Greenwich hour angle and declination of selected celestial bodies, plus additional celestial data used in navigation.

AIR DISTANCE (AD)—Distance that is measured relative to the mass of air through which an aircraft passes; the no-wind distance flown in a given time (TAS x time).

AIRPLOT (AP)—A continuous plot of a graphic representation of true heading and air distance.

AIR POSITION (AP)—The no-wind position of an aircraft at a given time.

AIRSPEED (AS)—The speed of an aircraft relative to its surrounding air mass.

Calibrated Airspeed (CAS)—Indicated airspeed corrected for pitot-static installation and/or the attitude of the aircraft.

Equivalent Airspeed (EAS)—Calibrated airspeed corrected for compressibility-of-air error.

Indicated Airspeed (IAS)—The uncorrected reading obtained from the airspeed indicator.

True Airspeed (TAS)—Equivalent airspeed corrected for density altitude (pressure and temperature).

AIRSPEED INDICATOR (ASI)—An instrument which gives a measure of the rate of motion of an aircraft relative to the surrounding air.

AIR TEMPERATURE

Basic Air Temperature (BAT)—Indicated air temperature corrected for the instrument error.

Corrected Mean Temperature (CMT)—The average between the target temperature and the true air temperature of flight level.

Indicated Air Temperature (IAT)—The uncorrected reading from the free air temperature gage.

True Air Temperature (TAT)—Basic air temperature corrected for the heat of compression error. Also known as outside air temperature (OAT).

AIRWAY—An air corridor established for the control of traffic and marked with radio navigation aids.

ALTER COURSE (A/C)—A change in course to a destination or a turning point.

ALTER HEADING (A/H)—The change in heading to make good the intended course.

ALTIMETER—An instrument that measures the elevation of an aircraft above a given datum plane.

ALTIMETER SETTING (ALT Set)—Station pressure reduced to sea level, expressed in inches of mercury or millibars. When this value is set into the altimeter, the instrument reading is indicated true altitude.

ALTITUDE—The height of an aircraft above a given datum.

Absolute Altitude (AA)—True altitude corrected for terrain elevation; the vertical distance of the aircraft above the terrain.

Basic Pressure Altitude (BPA)—Indicated pressure altitude corrected for instrument error. Also known as flight-level pressure altitude (FL PA).

Density Altitude (DA)—Basic pressure altitude corrected for temperature; the vertical distance of the aircraft above the standard datum plane.

Indicated Pressure Altitude (IPA)—The reading of the pressure altimeter with 29.92 set in the Kollsman window.

True Altitude (TA)—The density altitude corrected for pressure altitude variation (PAV); the vertical distance above mean sea level.

ALTITUDE, CELESTIAL—Angular distance of a celestial body above the celestial horizon, measured along the vertical circle.

Computed Altitude (Hc)—A mathematical computation of the correct celestial altitude of a body at a specific geographic position, for a given date and time.

Observed Altitude (Ho)—The sextant altitude corrected for sextant and observation errors.

Precomputed Altitude (Hp)—Computed celestial altitude corrected for all known observational errors and adjusted to the time of the observed altitude.

Sextant Altitude (Hs)—A celestial altitude measured with a sextant; the angle measured in a vertical plane between an artificial or sea horizon and a celestial body.

ALTITUDE DELAY—A controlled delay applied to the start of the trace to eliminate the altitude hole on the PPI-type display.

ALTITUDE HOLE—The blank area in the center of the PPI, the outer edge of which represents the point on the ground immediately beneath the aircraft.

ARIES, FIRST POINT OF (♈)—The point on the equinoctial where the sun moving along the ecliptic passes from south to north declination. Also known as vernal equinox.

ASSUMED POSITION (AP)—The geographic position upon which a celestial solution is based.

ASTRONOMICAL TRIANGLE—A triangle on the celestial sphere bounded by the observer's celestial meridian, the vertical circle, and the hour circle through the body, and having as its vertices the elevated pole, the observer's zenith, and the body.

AURAL NULL—The determination by ear of the point of zero or minimum audio signal from a radio compass, which occurs when the receiver radio signal picked up by the two sides of the rotatable loop antenna cancel one another. This point indicates that the plane of the loop is perpendicular to the direction of the transmitted signal and is used as a means of determining radio bearings in flight.

AZIMUTH ANGLE (Z)—The interior angle of the astronomical triangle at the zenith measured from the observer's meridian to the vertical circle through the body.

AZIMUTH STABILIZATION—Orientation of the picture on a radarscope so as to place true north at the top of the scope.

AZIMUTH, TRUE (Zn)—The angle at the zenith measured clockwise from true north to the vertical circle passing through the body.

BASE LINE—The line joining the master and slave Loran stations.

BASE LINE EXTENSION—The extension of the base line through and beyond the master and slave Loran stations.

BEACON—A ground navigational light, radio, or radar transmitter used to provide aircraft in flight with a signal to serve as a reference for the determination of accurate bearings or positions.

BEAM WIDTH—The effective width in azimuth of radiation from an antenna.

BEAM-WIDTH ERROR—An azimuth distortion of a radar display caused by the width of the radar beam.

BEARING—The horizontal angle at a given point, measured clockwise from a specific reference datum, to a second point. The direction of one point relative to another, as measured from a specific reference datum.

Magnetic Bearing (MB)—The horizontal angle at a given point, measured from magnetic north, clockwise, to the great circle through the object or body and the given point.

Relative Bearing (RB)—The horizontal angle at the aircraft measured clockwise from the true heading of the aircraft to the great circle containing the aircraft and the object or body.

True Bearing (TG)—The horizontal angle at a given point measured from true north clockwise to the great circle passing through the point and the object or body.

BELLAMY DRIFT—The net drift angle of the aircraft calculated between any two pressure soundings.

BLIP—The display of a received pulse on a CRT; a spot of light representing a target; (Loran) an upward deflection of the trace representing the received signal. Also known as pip.

BRANCH, LOWER—Half of an hour circle opposite from "upper branch," defined below.

BRANCH, UPPER—That half of an hour circle or meridian which contains the celestial body or the observer's position.

CELESTIAL EQUATOR—The great circle formed by the intersection of the plane of the earth's equator with the celestial sphere. Also known as Equinoctial.

CELESTIAL MERIDIAN—A great circle on the celestial sphere formed by the intersection of the celestial sphere and any plane passing through the North and South poles. Any great circle on the celestial sphere which passes through the celestial poles.

CELESTIAL NAVIGATION—See *Navigation Aids.*

CELESTIAL OBSERVATION ERRORS (Sextant)

Acceleration Error—An error caused by the deflection of the liquid in the bubble chamber due to any change in speed or direction of the aircraft.

Coriolis Error—The error introduced in a celestial observation taken in flight resulting from the deflective force on the liquid in the bubble chamber, as caused by the path of the aircraft in counteracting the earth's rotation.

Index Error—An error caused by the misalignment of the sighting mechanism of the instrument.

Parallax Error—The difference between a body's altitude above an artificial or visible horizon and above the celestial horizon. The error is present because of the fact that the body is not at an infinite distance.

Personal Error—Errors in celestial observations caused by sighting limitations of the observer, or visual interpretation which he uses in collimating the body during observations.

Refraction Error—An error caused by the bending of light rays in passing through the various layers of the atmosphere.

Rhumb-Line Correction—The correction applied for the bubble-acceleration error caused by the rhumb-line path of the aircraft.

Wander Error—The bubble-acceleration error caused by a change of track during the celestial-shooting period.

CELESTIAL POLES—The points of intersection of the extension of the earth's axis with the celestial sphere.

CELESTIAL SPHERE—An imaginary sphere of infinite radius whose center coincides with the center of the earth, on which all celestial bodies except the earth are imagined to be projected.

CHART—A graphic representation of a section of the earth's surface specifically designed for navigational purposes. A chart may also be referred to as a map. Although a chart is usually specifically designed as a plotting medium for marine or aerial navigation, it may be devoid of cultural or topographical data.

CHECK POINT—A geographical reference point used for checking the position of an aircraft in flight. As generally used, it is a well-defined reference point easily discernible from the air. Its exact position is known or plotted on the navigational chart, and was selected in preflight planning for use in checking aircraft position in flight.

CIRCLES

Circle of Equal Altitude—A circle on the earth which is the locus of all points equidistant from the subpoint of a celestial body. The altitude of a celestial body is the same measured from any point on the circle.

Diurnal Circle—The daily apparent path of a body on the celestial sphere caused by the rotation of the earth.

Great Circle—Any circle on a sphere whose plane passes through the center of that sphere.

Hour Circle—A great circle on the celestial sphere passing through the celestial poles and a given celestial body.

Small Circle—Any circle on a sphere whose plane does not pass through the center of that sphere.

Vertical Circle—A great circle which passes through the observer's zenith, nadir, and a body on the celestial sphere.

CO-ALTITUDE (co-alt)—The small arc of a vertical circle, between the observer's position and the body (90° — altitude).

CO-DECLINATION (co-dec)—See *Polar Distance*.

CO-LATITUDE (co-lat)—The small arc of the observer's celestial meridian, between the elevated pole and the body (90° — latitude).

COLLIMATION—The correct alignment of the images of the bubble of a sextant and the object being observed.

COMPASS—An instrument which indicates direction measured clockwise from true north, or grid north.

Direct-Indicating—A magnetic compass in which the dial, scale, or index is carried on the sensing element.

Magnetic—An instrument which indicates direction measured clockwise from magnetic north.

Remote Indicating—A magnetic compass, the magnetic sensing unit of which is installed in an aircraft in a position as free as possible from causes of deviation. A transmitter system is included so that the compass indication can be read on a number of repeater dials suitably placed throughout the aircraft.

COMPASS DIRECTION—The direction measured clockwise from a particular compass needle which is more often than not displaced from the magnetic meridian by local deviating magnetic fields.

COMPASS ROSE—A graduated circle on a map or chart, marked in degrees clockwise from 0° through 360° for use as a reference in measuring bearings and courses.

COMPASS SWING—A procedure for determining compass deviation on various aircraft headings for use in compensating or calibrating the compass. This can be done either on the ground or in the air.

CONSOL/CONSOLAN—A rotating radio signal system used for long range bearings.

CONSTELLATION—A recognizable group of stars by means of which individual stars may be identified.

CONTOUR LINES—Lines drawn on maps and charts joining points of equal elevation; also, a line connecting points of equal altitude on a constant-pressure chart.

CONTROLLED TIME OF ARRIVAL—A method of arriving at a destination at a specified time by changing direction and/or speed of an aircraft.

CONTROL POINT—The position an aircraft must reach at a predetermined time.

COORDINATES

Celestial (1)—The equinoctial system involves the use of sidereal hour angle and declination to locate a point on the celestial sphere with reference to the first point of Aries and the equinoctial.

Celestial (2)—The horizon system involves the use of azimuth and altitude to locate a point on the celestial sphere for an instant of time from a specific geographical position on the earth.

Celestial (3)—The Greenwich system involves the use of Greenwich hour angle and declination to locate a point on the celestial sphere with reference to the Greenwich meridian and the equinoctial for a given instant of time.

Geographical—The latitude and longitude used to locate any given point on the surface of the earth.

Grid—A system of coordinates in which the area concerned is divided into rectangles which are in turn subdivided, and in which the subdivisions or the dividing grid lines are designated by numbers and/or letters to serve as references in locating positions or small areas. Also a rectangular grid or fictitious chart graticule which is oriented with grid north.

Polar—A system of coordinates used in locating a point by direction and distance from an origin.

Rectangular—A system of coordinates based on a rectangular grid; sometimes referred to as grid coordinates.

CORIOLIS ERROR—See *Celestial Observation Errors.*

CORIOLIS FORCE—An apparent force due to the rotation of the earth which causes a moving body to be deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

COURSE—The direction of the intended path of an aircraft over the earth; or the direction of a line on a chart representing the intended aircraft path, expressed as the angle measured from a specific reference datum clockwise from 0° thru 360° to the line.

Great-Circle Course—The route between two points on the earth's surface measured along the shorter segment of the circumference of the great circle between the two points. A great circle course establishes the shortest distance over the surface of the earth between any two terrestrial points.

Grid Course—The horizontal angle measured clockwise from grid north to the course line. The course of an aircraft measured with reference to the north direction of a polar grid.

Magnetic Course—The horizontal angle measured from the direction of magnetic north clockwise to a line representing the course of the aircraft. The aircraft course measured with reference to magnetic north.

True Course (TC)—The angle measured clockwise from true north to the line representing the intended path of the aircraft.

Course Line—A line of position which is parallel or approximately parallel to the track of the aircraft. A line of position used to check aircraft position relative to intended course.

CRAB—A correction of aircraft heading into the wind to make good a given track; correction for wind drift.

CRUISE CONTROL—The operation of an aircraft to obtain the maximum efficiency on a particular mission (most miles per amount of fuel).

"D" SOUNDING—The difference between pressure altitude and true altitude as determined at a given time in flight (true altitude minus pressure altitude).

DATUM—Refers to a direction, level, or position from which angles, heights, depths, speeds, or distances are conventionally measured.

DAY

Civil Day—The interval of time between two successive lower transits of a meridian by the mean (or civil) sun.

Sidereal Day—The interval of time between two successive upper transits of a meridian by the first point of Aries (23 hours 56 minutes).

Solar Day—The interval of time between two successive lower transits of a meridian by the true (apparent) sun.

DEAD RECKONING—The directing of an aircraft and determining of its position by the application of direction and speed data to a previous position.

DEAD-RECKONING (DR) POSITION—The position of an aircraft determined for a given time by the application of direction and speed data only.

DECLINATION (dec)—The angular distance to a body on the celestial sphere measured north or south through 90° from the celestial equator along the hour circle of the body (comparable to latitude).

DEVIATION (dev)—Compass error caused by the magnetism within an aircraft; the angle measured from magnetic north eastward or westward to the direction of the earth's lines of magnetic force as deflected by the aircraft's magnetism.

DEVIATION CORRECTION—The correction applied to a compass reading to correct for deviation error. The numerical equivalent of deviation with the algebraic sign added to magnetic heading to obtain compass heading.

DIP

Celestial—The angle of depression of the visible sea horizon due to the elevation of the eye of the observer above the level of the sea.

Magnetic—The vertical displacement of the compass needle from the horizontal caused by the earth's magnetic field.

DIURNAL CIRCLE—See *Circles.*

DOG LEG—A route containing a major alteration of course (as opposed to a straight-line course.)

DOUBLE DRIFT (DD)—A method of determining the wind by observing drift on an initial true heading and two other true headings which are flown in a specific pattern. Also called multiple drift.

DRIFT—The rate of lateral displacement of the aircraft by the wind, generally expressed in degrees.

DRIFT ANGLE—The angle between true heading and track (or true course), expressed as degrees right or left according to the way the aircraft has drifted.

DRIFT CORRECTION (DC)—Correction for drift, expressed in degrees (plus or minus), and applied to true course to obtain true heading.

DRIFTMETER—An instrument used for measuring drift.

ECLIPTIC—The great circle on the celestial sphere along which the apparent sun, by reason of the earth's annual revolution, appears to move. The plane of the ecliptic is tilted to the plane of the equator at an angle of 23° 27′.

EFFECTIVE AIR DISTANCE (EAD)—The distance measured along the effective air path.

EFFECTIVE AIR PATH (EAP)—A straight line on a navigation chart connecting two air positions, commonly used between the air positions of two pressure soundings to determine effective true airspeed (ETAS) between the two soundings.

EFFECTIVE TRUE AIRSPEED (ETAS)—The effective air distance divided by the elapsed time between two pressure soundings.

ELEVATED POLE—That celestial pole which is on the same side of the equinoctial as the position of the observer.

EQUAL ALTITUDE—See *Circles.*

EQUATION OF TIME—The amount of time by which the mean sun leads or lags behind the true sun at any instant. The difference between mean and apparent times expressed in units of solar time with the algebraic sign, so that when added to mean time it gives apparent time.

EQUATOR—The great circle on the earth's surface equidistant from the poles. Latitude is measured north and south from the equator.

EQUINOCTIAL—See *Celestial Equator.*

EQUINOX

Autumnal Equinox—The point on the equinoctial when the sun, moving along the ecliptic, passes from north to south declination. This usually occurs on 21 September.

Vernal Equinox—The point on the equinoctial where the sun, moving along the ecliptic, passes from south to north declination. This usually occurs on 21 March.

FIELD-ELEVATION PRESSURE—The existing atmospheric pressure in inches of mercury at the elevation of the field. Also known as station pressure.

FIX—The geographic position of an aircraft for a specified time, established by navigational aids.

FLIGHT PLAN—Predetermined information for the conduct of a flight. That portion of a flight log that is prepared before the mission.

GEOREF—An international code reference system for reporting geographical position (similar to rectangular coordinates).

GEOSTROPHIC WIND—The mathematically calculated wind which theoretically blows parallel to the contour lines, in which only pressure-gradient force and Coriolis force are considered.

GRADIENT WIND—Generally accepted as the actual wind above the friction level, influenced by Coriolis force, pressure gradient, and centrifugal force.

GRATICULE—A system of vertical and horizontal lines that is used to divide a drawing, picture, chart, etc., into smaller sections. On a map the graticule consists of the latitude and longitude lines.

GREENWICH MERIDIAN—The prime meridian which passes through Greenwich, England, and from which longitude is measured east or west.

GRID NAVIGATION—A method of navigation using a grid overlay for direction determination.

GRIVATION (griv)—The angle between grid north and magnetic north at any point.

GROUND PLOT—A graphic representation of track and groundspeed.

GROUND RANGE—The horizontal distance from the subpoint of the aircraft to an object on the ground.

GROUND RETURN—The reflection from the terrain as displayed on a CRT.

GROUNDSPEED (GS)—The actual speed of an aircraft relative to the earth's surface.

GROUND WAVE—A radio wave that is propagated over the surface of the earth and tends to parallel the earth's surface.

HEADING—The angular direction of the longitudinal axis of an aircraft measured clockwise from a reference point.

Compass Heading (CH)—The reading taken directly from the compass.

Grid Heading (GH)—The heading of an aircraft with reference to grid north.

Magnetic Heading (MH)—The heading of an aircraft with reference to magnetic north.

True Heading (TH)—The heading of an aircraft with reference to true north.

HEAT-OF-COMPRESSION ERROR—The error caused by the increase in the indication of the free air temperature gage, due to air compression and friction on the case around the sensitive element.

HERTZ (Hz)—The standard unit notation for measure of frequency in cycles per second; i.e., 60 cycles per second is 60 Hz.

HOMING—A technique of arriving over a destination by keeping the aircraft headed toward that point by reference to radio, Loran, radar, or similar devices.

HORIZON

Bubble Horizon—An artificial horizon parallel to the celestial horizon, established by means of a bubble level.

Celestial Horizon—The great circle on the celestial sphere formed by the intersection of a plane passing through the center of the earth which is parallel to the plane tangent to the earth at the observer's position.

Visible Horizon—The circle around the observer where earth and sky appear to meet. Also called natural horizon or sea horizon.

HOUR ANGLE

Greenwich Hour Angle (GHA)—The angular distance measured from the upper branch of the Greenwich meridian westward through 360° to the upper branch of the hour circle passing through a point.

Local Hour Angle (LHA)—The angular distance measured from the upper branch of the observer's meridian westward through 360° to the upper branch of the hour circle passing through a body.

Sidereal Hour Angle (SHA)—The angular distance measured from the upper branch of the hour circle of the first point of Aries westward through 360° to the upper branch of the hour circle passing through a body.

HOUR CIRCLE—See *Circle.*

INDEX ERROR—See *Celestial Observation Error.*

INHERENT DISTORTION—The distortion of the display of a received radar signal caused by the design characteristics of a particular radar set.

INITIAL POINT (IP)—A preselected geographical position which is used as a reference for the beginning of a run on a target.

INTERCEPT, CELESTIAL—The difference in minutes of arc between an observed altitude of a celestial body and its computed altitude for the same time. This difference is measured as a distance in nautical miles from the plotting position along the azimuth of the body to determine the point through which to plot the line of position.

INTERNATIONAL DATE LINE—The antimeridian of Greenwich, modified to avoid island groups and land masses; in crossing this Greenwich anti-meridian there is a change of local date.

ISOBAR—A line joining points of equal pressure.

ISOGONIC LINE (Isogonal)—A line drawn on a chart joining points of equal magnetic variation.

ISOGRIV—A line drawn on a chart joining points of equal grivation.

ISOTACH—A line drawn on a chart joining points of equal wind speed.

ISOTHERM—A line drawn on a chart joining points of equal temperature.

KNOTS (k)—Nautical miles per hour.

LANDFALL—The first point of land over which an aircraft crosses when flying from seaward; also as used in celestial navigation, the procedure in which an aircraft is flown along a celestial line of position which passes through destination.

LATERAL AXIS—An imaginary line running through the center of gravity of an aircraft, parallel to the straight line through both wing tips.

LATITUDE (lat)—Angular distance measured north or south of the equator along a meridian, 0° through 90°

LINE OF CONSTANT BEARING—An unchanging directional relationship between two moving objects.

LINE OF POSITION (LOP)—A line containing all possible geographic positions of an observer at a given instant of time.

LOG—A written record of computed or observed flight data; generally applied to the written navigational record of a flight.

LONGITUDE (long)—The angular distance east or west of the Greenwich meridian, measured in the plane of the equator or of a parallel from 0° to 180°.

LONGITUDINAL AXIS—An imaginary line running fore and aft through the center of gravity of an aircraft, parallel to the axis of the propeller or thrust line.

LORAN—See *Navigational Aids*.

LUBBER LINE—A reference mark representing the longitudinal axis of an aircraft.

MACH NUMBER—The ratio of the velocity of a body to that of sound in the medium in which the craft is moving.

MAGNETIC DIRECTION—A direction measured clockwise from the magnetic meridian.

MAP READING—See *Navigational Aids*.

MAP SYMBOLS—Figures and designs used to represent topographical, cultural, and aeronautical features on a map or chart.

MARKER BEACONS—Radio beacons established at range stations, along airways, and at intermediate points between range stations to assist pilots and observers in fixing position.

Fan-Type—A 75-megaHertz radio transmitter usually installed at strategic points along a radio range across the on-course signal. The signal is produced in a space shaped like a thick fan immediately above the transmitter. The signal may be received visually or aurally, depending on the receiver.

M-Type—A low-powered, nondirectional radio station which transmits a characteristic signal once every few seconds. The range of the receiver is approximately 10 miles.

Z-Type—A special 75-megaHertz radio which transmits a signal within the cone of silence to enable the pilot to identify his position over the range station. The signal may be picked up visually or aurally depending on the receiver used. In Air Force aircraft, a marker-beacon light flashes on as the aircraft enters the cone of silence.

MASTER STATION—The primary or control transmitter station, the signal of which triggers the transmitter of one or more other stations. Also a transmitter station, the signals of which are used by other stations as a basis for synchronizing transmissions.

MEAN SEA LEVEL (MSL)—The average level of the sea, used to compute barometric pressure.

MEAN SUN—An imaginary sun traveling around the equinoctial at the average annual rate of the true sun.

MERIDIONAL PART—A unit of measurement equal to one minute of longitude at the equator.

MINIMAL FLIGHT PATH—A path which affords the shortest possible time en route, obtained by using maximum assistance from the winds.

MOST PROBABLE POSITION (MPP)—The computed position of an aircraft determined by comparing a DR position and an LOP or a fix of doubtful accuracy determined for the same time, in which relative weights are given to the estimated probable errors of each.

NADIR—The point on the celestial sphere directly beneath the observer's position.

NAUTICAL MILE (NM)—A unit of distance used in navigation, 6080 ft; the mean length of one minute of longitude on the equator; approximately 1 minute of latitude; 1.15 statute miles.

NAVIGATION AIDS—Any means of obtaining a fix or LOP as an aid to dead reckoning.

Celestial—The determination of position by reference to celestial bodies.

Consol/Consolan—A rotating radio-signal system used for long-range bearings.

Loran—An electronic aid to navigation whereby a line of position may be determined by measuring electronically the time difference between the receipt of pulsating signals of radio energy received from two different synchronized transmitting stations.

Map Reading—The determination of position by identification of land marks with their representations on a map or chart.

Pressure Differential—The determination of the average drift, or the crosswind component of the wind effect on the aircraft for a given period by taking "D" soundings and applying the formula

$$ZN = K \frac{(D_2 - D_1)}{ETAS}$$

where ZN is the cross wind component, K is the Coriolis constant, ETAS is the effective true airspeed, and D_1 and D_2 are the values of the pressure soundings.

Radar—The determination of position by obtaining information from a radar indicator.

Radio—The determination of position by the use of radio facilities.

NORTH

Compass North—The direction indicated by the north-seeking end of a compass needle.

Grid North (GN)—An arbitrarily selected direction of a rectangular grid. In grid navigation the direction of the 180° geographical meridian from the pole is almost universally used as standard grid north.

Magnetic North (MN)—The direction towards the north magnetic pole from an observer's position.

True North (TN)—The direction from an observer's position to the geographical North Pole. The north direction of any geographical meridian.

PARALLAX ERROR—See *Celestial Observation Errors.*

PERSONAL ERROR—See *Celestial Observation Errors.*

PITCH—Movement of an aircraft around the lateral axis.

PITOT—A cylindrical tube with an open end pointed upstream; used in measuring impact pressure, particularly in an airspeed indicator.

PITOT-STATIC TUBE—A parallel or coaxial combination of a pitot and static tube. The difference between the impact pressure and the static pressure is a function of the velocity of flow past the tube and may be used to indicate airspeed of an aircraft in flight.

POLAR DISTANCE—Angular distance from a celestial pole or the arc of an hour circle between the celestial pole and a point on the celestial sphere. It is measured along an hour circle and may vary from 0° to 180°, since either pole may be used as the origin of measurement. It is usually considered the complement of declination, though it may be either 90° —declination or 90° +declination, depending upon the pole used.

PRECESSION

Apparent—The apparent deflection of the gyro axis, relative to the earth, due to the rotating effect of the earth and not due to any applied forces.

Induced (Real)—The movement of the axis of a spinning gyro when a force is applied. The gyro precesses 90° from the point of applied pressure in the direction of rotation.

Of the Equinox—The average yearly apparent movement of the first point of Aries to the west.

PRECOMPUTED CURVE—A graphical representation of the azimuth and/or altitude of a celestial body plotted against time for a given assumed position (or positions), and which is computed for subsequent use for celestial observations. Used in celestial navigation for the determination of position, or to check a sextant.

PRESSURE ALTITUDE VARIATION (PAV)—The pressure difference, in feet, between mean sea level and the standard datum plane.

PRESSURE LINE OF POSITION (PLOP)—A line of position computed by the application of pressure pattern principles. Specifically, a line parallel to the effective air path and ZN distance from the air position for a given time. (See *Navigational Aids.*)

PROCEDURE TURN—A constant-rate turn of an aircraft in flight; used for computing the radius of turn and time required for its execution when very accurate navigation is required in controlling time or maintaining accurate, briefed tracks; usually associated with the turn made at the initial point of a bomb run to insure that the bombing run is made on the briefed axis of attack.

PROJECTION (CHART, MAP)—A process of mathematically constructing a representation of the surface of the earth on a flat plane.

PULSE DURATION OR PULSE WIDTH—The duration, in microseconds, of each pulse in a radar transmission.

PULSE-LENGTH ERROR—A range distortion of a radar return caused by the duration of the pulse.

PULSE RECURRENCE RATE (PRR)—The number of pulses transmitted per second by a radar or radio transmitter. Also known as pulse recurrence frequency (PRF).

PULSE RECURRENCE TIME (PRT)—The interval of time, in microseconds, between the transmission of two successive radar or radio pulses.

QUADRANTAL ERROR—The error in a radio direction indication introduced by the bending of radio waves by electrical currents and structural metal in the aircraft. It may also refer to magnetic-compass errors resulting from the same causes.

RADAR BEACON (RACON)—A stationary transmitter-receiver which sends out a coded signal when triggered by a radar pulse.

RADAR BEAM—A directional concentration of radio energy.

RADAR NAUTICAL MILE—The time required for a radar pulse to travel out one nautical mile and the echo pulse to return (12.4 ms).

RADIO COMPASS (ADF)—A radio receiver equipped with a rotatable loop antenna which is used to measure the bearing to a radio transmitter.

RADIO FREQUENCY (RF)—Any frequency of electrical energy above the audio range which is capable of being radiated into space.

RADIO NAVIGATION—See *Navigational Aids.*

RADIUS OF ACTION—The maximum distance that an aircraft can fly from its base before returning to the same or alternate base and still have a designated margin of fuel.

RADOME—A bubble-type cover for a radar antenna.

RANGE CONTROL—The operation of an aircraft to obtain the optimum flying time.

RANGE DEFINITION—The accuracy with which a radar set can measure range—usually a function of pulse shape.

RANGE, MAXIMUM—The maximum distance a given aircraft can cover under given conditions by flying at the economical speed and altitude at all stages of the flight.

REVOLUTION (of the earth)—The earth's elliptical path about the sun which determines the length of the year and causes the seasons.

RHUMB LINE—A line on the surface of a sphere which makes equal oblique angles with all meridians. A loxodromic curve.

ROTATION (of the the earth)—The spinning of the earth from west to east on its own axis which determines the days.

RUNNING FIX—A fix determined from a series of lines of position, based on the same object or body and resolved for a common time.

SCAN—The motion of a beam of RF energy caused by rotating or displacing the reflecting element or the antenna in relation to the reflecting element. The search pattern of an antenna.

SEMIDIAMETER (SD)—The value in minutes of arc of the radius of the sun or the moon.

SEXTANT—An optical instrument normally containing a two-power telescope with a 15° field of vision. It also contains a series of prisms geared to an altitude scale permitting altitude measurement of a celestial body's altitude from —10° below the horizon to 92° above the horizon.

SKY WAVES—A radio signal reflected one or more times from the ionosphere.

SLANT RANGE—Measurement of range along the line of sight.

SLAVE STATION—The station of a network which is controlled or triggered by the signal from the master station.

SOLSTICE—Those points on the ecliptic where the sun reaches its greatest northern or southern declination. Also the times when these phenomena occur.

Summer—That point on the ecliptic where the sun reaches its greatest declination having the same name as the latitude.

Winter—That point on the ecliptic where the sun reaches its greatest declination having the opposite name as the latitude.

SPEED LINE—A line of position that intersects the track at an angle great enough to be used as an aid in determining groundspeed.

SPOT-SIZE ERROR—A distortion of a radar return caused by the size of the electron spot in a cathode-ray tube.

STANDARD DATUM PLANE—An imaginary surface containing all points having a barometric pressure of 29.92 inches of mercury at a temperature of 15° centigrade. See *Altitude, Density*.

STANDARD LAPSE RATE

Temperature—A temperature decrease of approximately 2° centigrade for each 1,000 feet increase in altitude.

Pressure—A decrease in pressure of approximately 1 inch of mercury for each 1,000 feet.

STAR MAGNITUDE—A measure of the relative apparent brightness of stars.

STATUTE MILE—5,280 feet or .867 nautical miles.

SUBPOINT—That point on the earth's surface directly beneath an object or celestial body.

SUN LINE—A line of position obtained by computation based on observation of the altitude of the sun for a specific time.

SWEEP—The luminous line produced on the screen of a cathode ray tube by deflection of the electron beam. Also called time base line. See *Trace*.

SWEEP DELAY—The electronic delay of the start of the sweep used to select a particular segment of the total range.

TARGET-TIMING WIND—A wind determined from a series of ranges and bearings on the same target taken within a relatively short period of time.

TIME

Apparent Time—Time measured with reference to the true sun. The interval which has elapsed since the last lower transit of a given meridian by the true sun.

Greenwich Apparent Time (GAT)—Local time at the Greenwich meridian measured by reference to the true sun. The angle measured at the pole or along the equator or equinoctial (and converted to time) from the lower branch of the Greenwich meridian westward through 360° to the upper branch of the hour circle passing through the true (apparent) sun.

Greenwich Mean Time (GMT)—Local time at the Greenwich meridian measured by reference to the mean sun. It is the angle measured at the pole or along the equator or equinoctial (and converted to time) from the lower branch of the Greenwich meridian westward through 360° to the upper branch of the hour circle through the mean sun.

Greenwich Sidereal Time (GST)—Local sidereal time at Greenwich. It is equivalent to the Greenwich hour angle of Aries converted to time.

Local Apparent Time (LAT)—Local time at the observer's meridian measured by reference to the true sun. The angle measured at the pole or along the equator or equinoctial (and converted to time) from the lower branch of the observer's meridian westward through 360° to the upper branch of the hour-circle passing through the true (apparent) sun.

Local Mean time (LMT)—Local time at the observer's meridian measured by reference to the mean sun. It is the angle measured at the pole or along the equator or equinoctial (and converted to time) from the lower branch of the observer's meridian westward through 360° to the upper branch of the hour circle through the mean (or average) sun.

Local Sidereal Time (LST)—Local time at the observer's meridian measured by reference to the first point of Aries. It is equivalent to the local hour angle of Aries converted to time.

Mean Time—Time measured by reference to the mean sun.

Sidereal Time—Time measured by reference to the upper branch of the first point of Aries.

Standard Time—An arbitrary time, usually fixed by the local mean time of the central meridian of the time zone.

Zone Time—The time used throughout a 15° band of longitude. The time is based on the local mean time for the center meridian of the zone.

Z or Zulu Time—An expression indicating Greenwich mean time. Usually expressed in four numerals (0001 through 2400).

TIME ZONE—A band on the earth approximately 15° of longitude wide, the central meridian of each zone generally being 15° or a multiple removed from the Greenwich meridian so that the standard time of successive zones differs by one hour.

TRACK (Tr)—The actual path of an aircraft over the surface of the earth, or its graphic representation; also called track made good.

TWILIGHT—That period of day, after sunset or before sunrise, when the observer receives sunlight reflected from the atmosphere.

Astronomical Twilight—That period which ends in the evening and begins in the morning when the sun reaches 18° below the horizon.

Civil Twilight—That period which ends in the evening and begins in the morning when the sun reaches 6° below the horizon.

Nautical Twilight—That period which ends in the evening and begins in the morning when the sun reaches 12° below the horizon.

VARIABLE RANGE MARKER (VRM)—An electronic marker, variable in range, displayed on a CRT, for purposes of accurate ranging; sometimes called bomb-release pip.

VARIATION (var)—The angle difference at a given point between true north and magnetic north expressed as the number of degrees which magnetic north is displaced east or west from true north. The angle to be added algebraically to true directions to obtain magnetic directions.

WIND—Moving air, especially a mass of air having a common direction or motion. The term is generally limited to air moving horizontally or nearly so; vertical streams of air are usually called currents.

WIND DIRECTION AND FORCE—The direction from which, and the rate at which, the wind blows.

WIND DIRECTION AND VELOCITY (W/V)—Wind direction and speed. Wind direction is the direction from which the wind is blowing expressed as an angle measured clockwise from true north. Wind speed is generally expressed in nautical miles or statute miles per hour.

YEAR, APPARENT SOLAR—The period of time between two successive passages of the mean sun through the first point of Aries. It has a mean value of 365 days 05 hours 48.75 minutes. This period contains one complete cycle of the seasons and is less than the sidereal year owing to the precession of the equinoxes.

YEAR, SIDEREAL—The period of time between two successive passages of the sun across a fixed position among the stars. Its value is constant, and equal to 366 days 06 hours 09 minutes, a true measure of the earth's period of orbital revolution.

ZENITH—The point on the celestial sphere directly above the observer's position.

ZENITH DISTANCE (ZD)—The angular distance from the observer's position to any point on the celestial sphere measured along the vertical circle passing through the point. It is equivalent to co-altitude, but when applied to a body's subpoint and the observer's position on the earth it is expressed in nautical miles.

ZN (Pressure Pattern Displacement)—In pressure pattern flying, the displacement in nautical miles, at right angles to the effective airpath, due to the crosswind component of the geostrophic wind.

ATTACHMENT 4

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